NCHRP

SYNTHESIS 548

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Development and Use of As-Built Plans by State Departments of Transportation

A Synthesis of Highway Practice

The National Academies of
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 548

Development and Use of As-Built Plans by State Departments of Transportation

A Synthesis of Highway Practice

Tim Taylor
Victoria Lasley
Steve Waddle
Ying Li
UNIVERSITY OF KENTUCKY
Lexington, KY

Roy Sturgill
IOWA STATE UNIVERSITY
Ames, IA

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2020

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the National Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the FHWA. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP SYNTHESIS 548

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ABOUT THE NCHRP SYNTHESIS PROGRAM

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-05, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, Synthesis of Highway Practice.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

FOREWORD

By Tanya Zwahlen
Staff Officer
Transportation Research Board

The objective of *NCHRP Synthesis 548* was to examine the current state of the practice in as-built development and use across the United States. The report documents how state departments of transportation define as-built plans, the information being documented and included on as-built plans, and the methods used to capture and document changes to design plans during construction.

The state of the practice was examined by reviewing the literature related to as-built creation and usage, reviewing publicly available state transportation agency policies and procedures related to as-builts, sending an online survey to state transportation agencies, and conducting interviews with state transportation agencies that led to the development of case examples describing the as-built processes at selected agencies.

Current and former team members at the University of Kentucky collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on page iv. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Development and Use of As-Built Plans by State Departments of Transportation

Construction as-built plans have been an integral part of the transportation network management process for decades. While the process varies from state to state, as-builts have traditionally been "marked up" plan sets that denote any changes to the project that occurred during the construction project development phase. Initially, these modifications and notes were recorded on a physical set of drawings that were then stored in a designated location to be accessed when future needs arise (e.g., roadway improvement, significant maintenance activities). Over time, the storage of as-builts has shifted from paper copy to microfilm or microfiche and now to electronic and digital storage. As-builts contain information that is important to highway design, structural design, and road and bridge maintenance.

As highway system management has evolved, the as-built processes at most state transportation agencies (STAs) have lagged behind. Despite the efforts of agency personnel, as-built information is often not recorded, or, even worse is recorded but remains inaccessible to users of as-built information. Construction divisions are most often tasked with creating as-built plans, yet the information they collect is used by others. As-builts are typically created at the end of the project at a time when all project stakeholders are transitioning to the next project. The time between as-built creation and as-built use is measured in multiple years or decades.

Over time, the use and need of as-builts has evolved as well. Commercial software such as Google Earth provides designers with a street-level view of most roads in the United States. LiDAR can provide survey-grade point clouds of a potential project in a few days of effort. Information technology (IT) systems allow the near-instantaneous flow of data between project stakeholders. In light of these advancements, the traditional as-built process may not meet the current needs of infrastructure management. Collecting different types of as-built data than have historically been collected might be considered. In human resource–constrained STAs, the current as-built creation and distribution processes may not be efficient.

This synthesis examines the current state of the practice in as-built development and use across the United States. The state of practices was examined through a review of literature related to as-built creation and usage, a review of publicly available STA policies and procedures related to as-builts, an online survey of STAs, and case examples describing the as-built process at selected agencies. Forty-two states (84%) responded to the online survey. The information gathered from the literature review and the survey was used to select states to be showcased as case examples. The key findings of the synthesis are as follows:

- Of the survey respondents, 68% indicated their agency has a documented process for as-built development.

- States indicated that handwritten notes (86%) were the most commonly used method to capture as-built data, followed by electronic notes (76%) and then photographs (33%). Some states use more than one option to capture as-built data.
- Advanced technology has changed the accuracy and detail of project plans; however, it seems new technology has not had the same effect on as-built plans.
- As-builts are typically created by the construction division within STAs. Approximately half of the respondents indicated that as-builts were developed by only agency personnel, and the other half indicated that as-builts were developed using a mix of agency staff, contractors, and/or construction, engineering, and inspection (CEI) consultants.
- The majority of respondents indicated that as-builts were stored electronically, but 57% indicated that as-builts are also stored on paper hard copy.

The synthesis identifies several gaps in knowledge that could be addressed through future study, including the following:

- Improvement in as-built data capture methods was the most frequently cited (94% of respondents) area of needed improvement in current STA as-built processes.
- Improving the overall process of the as-built creation process is currently a focus for STAs.
- The most significant obstacles that STAs face in improving their current as-built process are limitations in staff knowledge and technology and the availability of human resources to complete as-builts.

CHAPTER 1

Introduction

Background

Over the years, as-built plans have been the method used by the construction industry to capture and record construction changes and additions that are not represented in the original plan drawings. The accuracy and completeness of these plans are essential for operations, maintenance, and rehabilitation of current transportation infrastructure. As-builts also provide a baseline for new design projects by providing information on current transportation infrastructure and other facilities such as underground and overhead utilities. The purpose of this synthesis was to canvas state transportation agencies (STAs) and establish the state of the practice for as-built development, preservation, and usage.

The United States is facing an infrastructure crisis, as current transportation infrastructure is deteriorating and failing. The 2017 American Society of Civil Engineers (ASCE) Report Card gave America's overall infrastructure a score of D+ with roads and bridges receiving grades of D and C+, respectively (2017). As engineers begin to rebuild the current infrastructure, as-built plans can provide important insight into existing infrastructure systems.

While the importance of as-built plans is widely recognized, current as-built development practices are often outdated and inefficient. According to a virtual design and construction engineer and affiliate member of ASCE, "Significant losses have been noted because of the difficulty in obtaining information about existing assets, such that over US$5.4 billion is wasted per year on operations and maintenance engineers verifying the accuracy of existing information and transferring information related to existing U.S. capital facilities" (Randall 2011). Over the last decade, the construction and transportation industry has adopted advanced data collection methods utilizing technologies such as LiDAR, three-dimensional (3-D) information modeling, ground-penetrating radar, and e-construction tools. These technologies have changed the format, accuracy, and level of detail available for transportation projects, and have allowed designers to include more accurate information on construction plans. While electronic and 3-D technology is becoming the norm for engineering practices, some entities still choose to hand-draw as-built information on the original construction plans.

This work examines current as-built practices within STAs and offers suggestions to future work needed to improve the accuracy and efficiency of as-built collection.

Project Scope and Objectives

The scope of this study objective was limited to the analysis of information collected from literature, survey responses, and case-based interviews. With this in mind, the research team, with guidance from the research panel, developed data collection tools with the goal of

collecting the following types of information relative to as-built development, preservation, and usage:

- How STAs define as-built plans;
- Information being documented and included on as-built plans;
- Methods used to capture and document changes to design plans during construction;
- Platforms used to establish the as-built plans (e.g., paper markups, electronic models);
- Entity used to develop as-built plans;
- How as-built plans are approved;
- How as-built plans are retained and preserved;
- How as-built plans are used once approved (e.g., asset management);
- Since approved as-built plans are legal documents, how STAs store and retrieve information from approved as-built plans for legal purposes;
- How STAs capture information for as-built plans from third-party agencies; and
- How as-built plans may differ for various types of delivery methods, including design–bid–build, design–build, construction manager/general contractor, and public-private partnerships.

The objective of this synthesis was to document how as-built plans are developed, used, and updated for various delivery methods by STAs. This synthesis focused on as-built development practices and successful application of new technologies and methods in as-built development and usage. This synthesis also looked to understand the coordination between as-built developers and end users.

The synthesis highlights the state of the practice so that efforts can be made to fill study gaps and establish a path to improvement. Some issues facing as-built development include IT issues, a lack of technical staffing, a lack of management support, uncertainty about where to begin, and a lack of available technology.

Study Methodology

The fundamental aspect of the study methodology was the survey of STAs to establish a state of the practice regarding as-built development, preservation, and usage for various delivery methods. The survey was sent to voting members on AASHTO's Design and Construction Committees and received a response rate of 84% (42 of the 50 STAs surveyed).

To support the development of the survey and the compilation of this synthesis, a literature review was conducted on topics related to as-built development, preservation, and usage. Much of this review focused on as-built practices at STAs found in publicly available manuals and guidelines, but it also included a review of as-built practices throughout other segments of the construction industry.

With regard to the surveys, the full questionnaires can be found in Appendix A. The survey gathered information regarding the following:

- As-built development processes,
- As-built approval processes,
- As-built storage methods and formats,
- As-built usage,
- Future opportunities for as-built processes, and
- Study and knowledge gaps.

Concurrent with the final stages of the survey questionnaire, STAs were identified for follow-up interviews via literature review and initial survey responses. Representatives from six states—Arizona, Colorado, Kentucky, Minnesota, Virginia, and Wisconsin—were interviewed.

The interviewees were selected not only to achieve diversity in size and complexity of the agencies, but also to question those with varied and innovative as-built procedures. The goal of the interviews was to provide depth to the information gathered from the survey. Specific details collected in the interviews include the following:

- Differences in as-built procedures based on project delivery method;
- Incorporation of as-built data into asset management;
- Recent development of as-built web pages, databases, and management systems; and
- Overall as-built procedures.

This report synthesizes the findings about the state of the practice of as-built development, preservation, and usage. The authors' charge in this report is strictly to present information collected void of opinion and bias. The opinions expressed in the synthesis from detailed case examples are those of the as-built professionals and should be viewed as such. The report is organized as follows:

- Chapter 2 is a review of Department of Transportation (DOT) manuals on as-built process,
- Chapter 3 summarizes survey results,
- Chapter 4 provides six case examples of current as-built processes, and
- Chapter 5 draws conclusions based on findings in previous chapters.
- Appendix A contains a survey questionnaire for STAs.
- Appendix B contains the results of the survey questionnaires.
- Appendix C contains case example interview questions.

CHAPTER 2

Review of State DOT Literature on the As-Built Process

A literature review was conducted to analyze the methods in which the STAs and other engineering and construction firms conduct as-built operations. Not much academic literature has put the focus on as-built processes for highway construction projects; therefore, the literature review effort mainly focused on STAs' published manuals. Information of interest included the entity responsible for as-built development, the methods used to capture and record as-built information, the platforms used to establish as-built plans, the information recorded on as-built plans, the accuracy and usefulness of as-built plans, the format and location in which as-built plans are stored, and the use of as-built plans after they are approved.

As-Built Practices in State Transportation Agencies

A web review of all 50 STAs was conducted to summarize the state of the practice regarding as-built procedures for each STA. Forty-two STAs had publicly available documented as-built related practices and requirements in their manuals or specifications. The final synthesis included as-built information from 17 STA specifications, 28 construction manuals, seven design manuals, and eight other manuals and guides found on 38 STA websites. Figure 1 depicts which online publication contained descriptions of the as-built processes for each of the 38 STAs.

The data summarized in the following table are based on publicly available STA guidelines (accessed between December 2017 and February 2018), and may not necessarily describe current practices (i.e., it is possible that current practice at some STAs is not consistent with a published as-built process). For example, it is unlikely that STAs are still archiving as-built information on microfiche. Table 1 summarizes each STA's as-built practices and lists the processes used to record as-built information for all 33 STAs in which this information was provided in their publicly available manuals.

The entity that develops as-builts for STAs was grouped into one of the following categories: in-house completed as-builts, in-house or design consultant–completed as-builts, contractor-completed as-builts, or in-house or contractor-completed as-builts. Thirty-five state manuals identified the entity responsible for developing their as-builts. The categorical breakdown was as follows: 23 STA manuals have in-house employees creating as-builts, seven have in-house personnel or design consultants creating as-builts, three have contractors creating as-builts, and two STAs list in-house personnel or the contractor creating as-builts. Results are displayed in Figure 2.

While only five STA manuals assign the contractor as the lead for as-built development, 19 manuals have the contractor developing some type of as-built drawings even though they are not identified as the party responsible for as-built development. Most of these additional

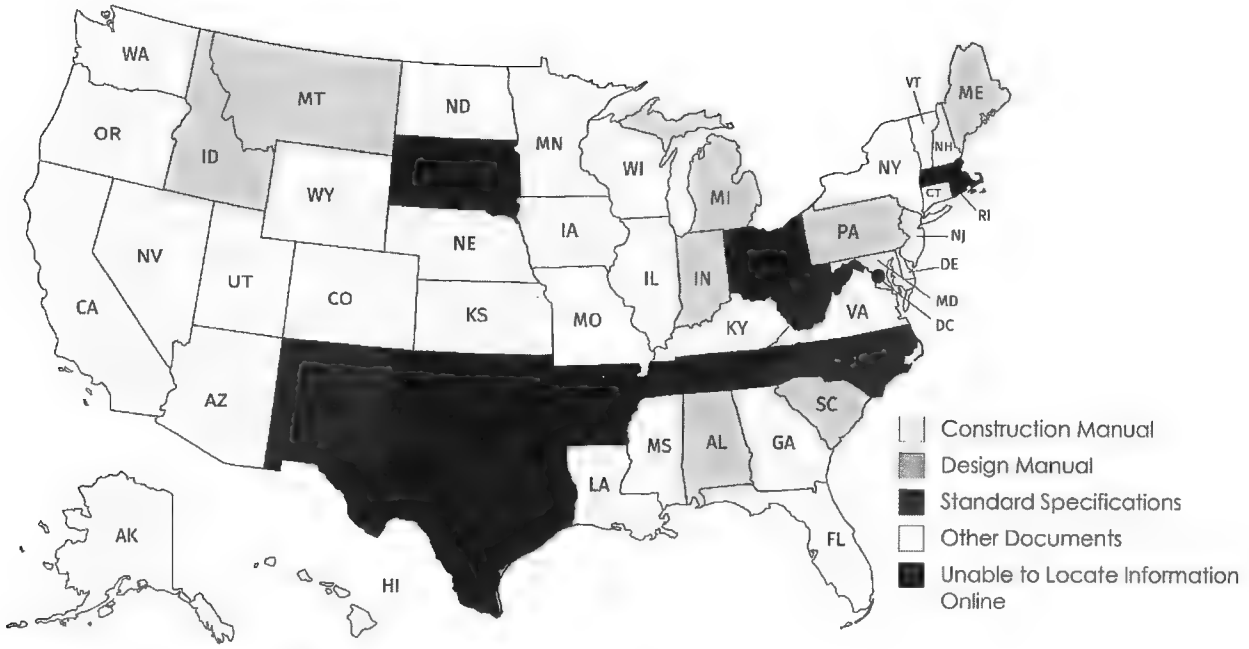


Figure 1. STA manual detailing as-built practices.

Table 1. STA as-built practices.

STA	Entity Responsible for As-Built Development	As-Built Development Process	Format of Stored As-Builts	Storage Location of Completed As-Builts
AK	Project Engineer	Updated by hand and either copied to Mylar or used to redraft original drawings.	Hard-copy prints	
AZ	Construction Administrator and As-Built Designer	One of three ways: (1) updated by hand and scanned to PDF, (2) updated electronically, or (3) updated by hand and transcribed electronically using MicroStation or Adobe.	PDF	Repository of Online Archived Documents (ROAD)
CA	Resident Engineer and the District Design Unit or a Consultant	Full-sized drawings updated by hand or by a field computer-assisted drafting (CAD) system, then transferred to original CAD files by design unit or consultants.	TIFF file and microfilm	Document Retrieval System
CO	Project Engineer	Copy of original plans revised using MicroStation, Redline Software, or similar software.	Hard-copy prints and electronic	Electronic copies are retained by the resident engineer and hard copies are distributed.
CT	Chief Inspector and/or Designer	District management decides how as-builts are developed and by whom.	PDF	ProjectWise
DE	Resident Engineer/Project Supervisor	Updated by hand with a red pencil. These plans are used to update original construction plans.	Hard-copy prints	
FL	Project Personnel and the District Finals Estimate Office or Consultant	Updated electronically; project personnel mark changes in red, while the overviewer makes comments in green.	PDF	Electronic Document Management System

(continued on next page)

Table 1. (Continued).

STA	Entity Responsible for As-Built Development	As-Built Development Process	Format of Stored As-Builts	Storage Location of Completed As-Builts
GA	Project Personnel under the supervision of the Construction Manager	Updated by hand in red and scanned.	Electronic	ProjectWise
HI	Contractor	Updated by hand; changes are made with a red pencil and notes are made with a blue pencil.	Hard-copy prints	
ID	Resident Engineer or Contractor	Plans need to be updated using CAD if CAD was used to prepare the original project plans.	PDF	File360 Image Database
IL	Resident Engineer	Updated by hand.	Microfilm	Microfilm Unit
IN	District Office		Hard-copy prints or microfilm	Appropriate district office
IA	Project Engineer	Full-sized plans updated by hand or electronic plans updated using Spicer Imagination Software.	Hard-copy prints or electronic	Records management for hard-copy prints or Electronic Record Management System for electronic plans
KS	Field Engineer and Bureau Chief of Road Design	Updated by hand with black ink and used to update the original tracings.	Hard-copy prints	District office files
KY	Section Engineer	Updated by hand.	Microfilm	Department of Library and Archives
LA	Project Engineer	Updated by hand with red pen or pencil.	Hard-copy prints	
ME			Electronic	E-Plans archive on Maine DOT intranet page
MD	Project Engineer	Updated by hand in green. May be scanned if all groups agree.	Hard-copy prints or electronic if approved	
MI	Resident/Delivery Engineer	Updated by hand with black ink or in CAD.	PDF	ProjectWise
MN	Project Engineer	Updated by hand in ink.	Microfilm	
MS	Project Engineer	Half-sized plans are updated with red ink.	Hard-copy prints	
MO	Resident Engineer	Need to be updated using MicroStation. If MicroStation is not used, black ink or Mylar pencils must be used.	CD	
MT			Hard-copy prints or electronic	Montana DOT Central Office if not available electronically
NE	Consultant or Project Manager	Full-sized plans are updated with black ink. Half-sized copies are made for districts.	Microfilm	
NV	Construction Field Crew	Updated by hand with blue ink and scanned.	Hard-copy prints and electronic	Hard-copy prints are stored in the district and headquarter offices. Bridge project as-builts are stored in Central Records.

Table 1. (Continued).

STA	Entity Responsible for As-Built Development	As-Built Development Process	Format of Stored As-Builts	Storage Location of Completed As-Builts
NJ	Resident Engineer and Designer	Updated by hand with red pencil, then transferred to project Mylars.	Mylars	Document Control
NM	Contractor or Contractor's Personnel	Full-sized plans updated with black ink.	Electronic and hard-copy prints if electronic survey data are provided. If not, just hard-copy prints.	
NY	Regional Construction Engineer or Designee and Regional Construction Group	Updated by hand and used to develop final as-builts in CAD.	PDF	ProjectWise
ND	Project Engineer	Updated by hand or electronically with changes made in blue.	Microfilm	
OR	Project Manager	Updated by hand in red then scanned.	PDF	FileNet
PA	Department or Consultant		PDF	Electronic Document Management System
SC	Resident Construction Engineer or Contractor	Updated by hand or in CAD in red.	Hard-copy prints or electronic	Plans Library
UT	Contractor	Updated by hand in red and scanned or used to modify the original CAD files.	Electronic	ProjectWise
VT	Resident Engineer and Finals Room Supervisor or Their Designee	Updated by hand in red ink and scanned or used to modify the original CAD files.	Hard-copy prints and CAD or TIFF files	Digital Print Room
VA	Inspector	Updated by hand and used to develop CAD files.	CAD file	Central Office Structure and Bridge File Room
WA	Project Engineer	Full-sized plans updated in red ink.	PDF	Oracle Content Management System
WI	Project Leader	Updated in red using Adobe Acrobat Professional or equivalent Adobe software.	PDF	DOTView Image Drive
WY		As-built summaries must be included in as-built plans. Utility as-builts must go to the district maintenance technician.		

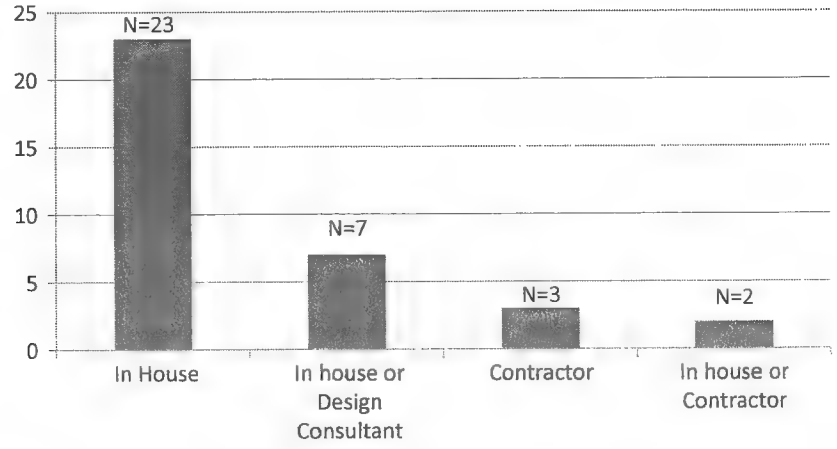


Figure 2. Entity responsible for as-built development for STAs.

contractor-created as-builts are for specialty items such as electrical work, irrigation systems, or water and sewer systems. However, Colorado and Connecticut have the contractor develop complete-project as-built drawings to assist the responsible party in completing the official as-builts. Table 2 lists as-builts required to be completed by contractors for corresponding STAs.

While as-built plans have been the method used to document changes during construction projects over several decades, the processes and methods used to capture as-built information are continuously changing as new technology emerges. Recently, LiDAR, information modeling, and GPS technologies have changed the way the transportation industry collects data and develops plans, making them more accurate and detailed. While some construction firms and companies are utilizing these technologies for as-built development according to published manuals, most STAs are not. It is possible that some STAs started using these technologies after the manuals were last updated online. Thirty-three STAs provided information on the method

Table 2. Contractor created as-builts.

STA	Contractor Created As-Builts
AL	Utilities
AK	Specialty items such as electric and structures
AZ	Survey information
CA	Irrigation systems, prestressed concrete structures, and electrical wiring diagrams
CO	All changes and deviations
CT	All changes and deviations
FL	Intelligent transportation systems (ITS), signals, conduits, and lighting
GA	Water and sewer facilities
IL	Electrical work
IN	Permanent earth-retention systems and wiring diagrams
KS	Survey information
MS	Roadway lighting systems and centerline elevations
NH	Inductive loops
NJ	Water, sewer, gas, highway lighting systems, ITS, fiber optic cables, and traffic signal systems
NC	Utilities and buried electrical circuits for roadway lighting systems
OR	Irrigation systems
VA	Topographic survey information
WA	Corrected shop drawings, schematic circuit diagrams, or other drawings necessary to help prepare final as-builts
WV	Drilled caisson as-builts, as-built utility surveys, and as-built shop drawings

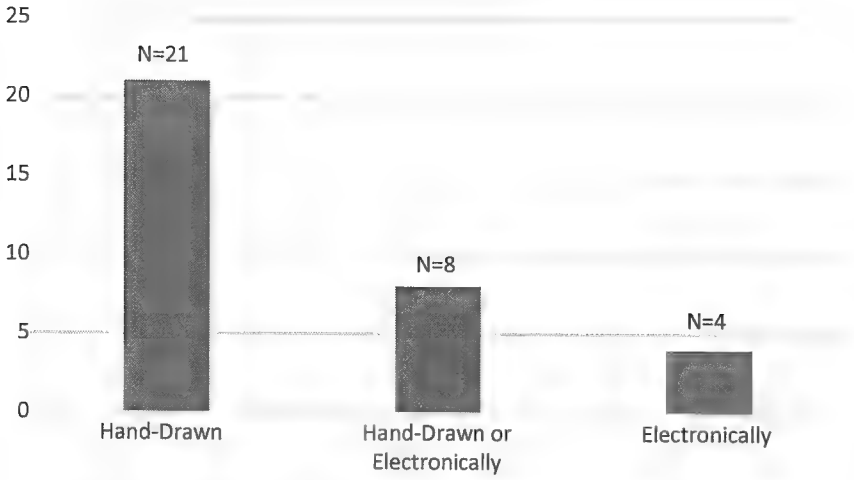


Figure 3. Method used to record as-built information for STAs.

used to record as-built information (Figure 3). According to publicly available STA guidelines, 21 STAs still require the initial set of as-built plans to be developed by hand. Several STAs then scan or copy these initial as-builts to electronic files such as PDF or CAD (computer-assisted drafting). Eight STAs allow as-built to be developed manually or electronically, and only four STAs require as-builts to be developed electronically from the beginning. Results are displayed in Figure 3.

The format in which as-builts are stored for various STAs was also examined. Thirty-seven states documented how their agency stores completed as-builts. The formats were categorized in one of the following: microfilm, hard-copy prints, or electronically stored plans. The categorical breakdown was as follows: five STAs store as-builts as microfilms, seven store as-builts as hard copies, 15 store as-builts electronically, five require more than one form of as-builts to be stored, and five provide options for as-built storage. A visual representation of the results can be found in Figure 4.

Ten STAs that store as-built plans electronically require they be stored in PDF format. The location in which as-built plans are stored relates to the format in which they are stored. The majority of the STAs that are storing as-built plans electronically are storing them in electronic

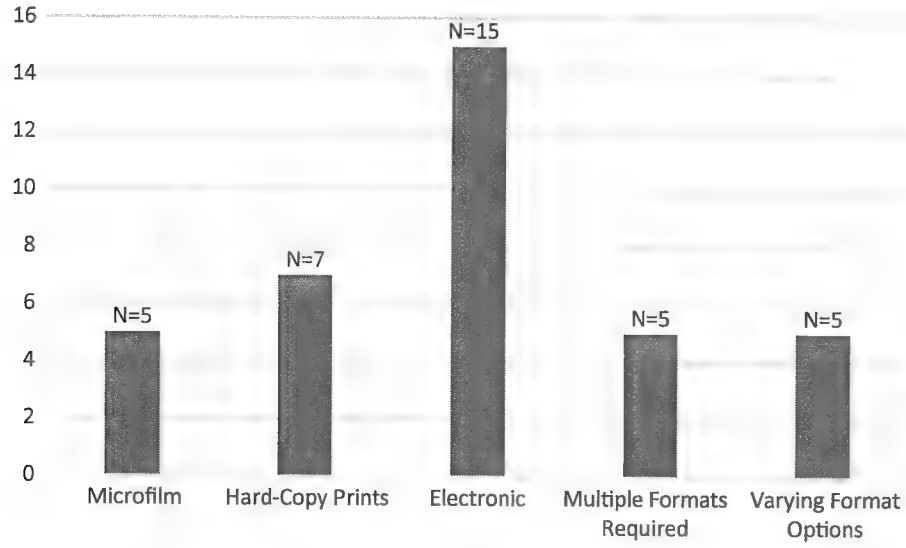


Figure 4. Format of stored as-builts for STAs.

document management systems (EDMSs), while storage locations for the other formats vary by STA. As-built storage formatting and location for STAs can be found in Table 1.

In order for as-builts to be useful beyond their creation, it is imperative to identify information about the project that will be needed by operators, maintenance crews, and others in the future. To accomplish this, it is ideal that individuals or entities who will maintain the facility or infrastructure have a say in what will be included in the as-built plans (Whyte et al. 2016). Several STAs mention in their manuals and specifications what information should be recorded on their as-built drawings. Common required revisions to be recorded on as-built plans throughout STAs include the following:

- Changes in horizontal and vertical alignment;
- Grade revisions;
- Corrections and adjustments to stationing;
- Changes in typical sections;
- Utility locations, depths, elevations, offsets, and clearances;
- Changes to right-of-way lines, distances, and markers;
- Changes to drainage structures such as length, flow line elevation, station or offset dimensions, sizes, thicknesses, and types of inlets and manholes;
- Location and elevation of monuments, benchmarks, freeway fences, and gates;
- Locations and dimensions of all structures; and
- Foundation elevations and subsurface structural details.

As-Built Practices in Comparison with Private Industry

The information provided in STA construction manuals, design manuals, and specifications gave insight into how as-builts should be developed and how and where they should be stored. However, there is little to no mention of the handover of the as-built plans from their developers to their potential users or how they are used after completion. The process of developing and storing as-builts according to guidelines, and accessing them several years down the road when needed, may not be an issue with hand-drawn as-builts developed according to agency standards. However, with changing technologies, there is a need for proper communication and handover techniques between as-built developers and end users. A review of private-industry as-built practices offered insight on the importance of communication between as-built developers and end users during the as-built development process. It also provided information on the potential for 3-D technologies, such as Building Information Modeling (BIM) and LiDAR, in the as-built development process (Randall 2011). No STA listed the use of these technologies in its publicly available manuals and guidelines.

As technology improves and as-builts become digital and more detailed, the handover process will also be more detailed. The transfer of as-built data will require "attention to sequence, timing, passing technique and communication within a time-constrained window of opportunity" (Whyte et al. 2016). Improving the transfer of as-built information will enable owners, operators, maintenance workers, and any others who will need the as-built information in the future to better manage and maintain the infrastructure. This can require meetings with all current and future project teams to discuss the handover procedure and what data each group needs at the end of construction. The handover phase must be planned and practiced before it arrives (Whyte et al. 2016). Utah is an example of an STA that practices this handover method. Contractors and engineers engage in a preconstruction conference in which the engineer clearly defines what he or she expects on the as-builts for the particular project. Without proper and planned transfer, information is likely to be lost or misinterpreted.

The timing of the handover is arguably the most important aspect of the handover procedure. If the handover process is not given adequate time, mistakes are more likely to be made. Ideally, the physical act of handing over as-built data can only occur once the task or project is complete and all information has been updated. However, the buildup for handover needs to begin during the design phase. This involves continuously updating plans and digital data to the as-built condition throughout the project. If changes to the project are not recorded until the end, as-builts are often rushed and mistakes are likely to be made (Whyte et al. 2016). Fourteen STAs require as-built plans to be maintained throughout the project duration.

Another major challenge in data handover is the accuracy and completeness of the data. In the past, as-built plan development has been a manual process that is error prone (Abdel-Monem and Hegazy 2013). As-builts often consist of hundreds of plan drawings with unknown accuracy (Randall 2011). However, it is essential that as-built data be accurate and of high quality for them to be trusted and used in decision making. Because of the potential for inaccuracies, data and as-builts information are often not used even when available (Whyte et al. 2010). For example, an Olympic Delivery Authority grounds work and services manager said, when asked about trust in data for built infrastructure, "Unless you're really on top of it, once the data is no longer trusted people stop using it and then it just is a waste, completely falls away" (Whyte et al. 2016). Few STAs mentioned required accuracy of as-built plans, and most had vague descriptions (e.g., "The as-built plans should be carefully and accurately prepared"). The Connecticut Department of Transportation requires field personnel to receive training from engineers before they can develop electronic as-builts to ensure accuracy, high quality, and consistency.

Technology advancements will assist with the improvement of quality and accuracy of as-builts in the future. BIM is a 3-D representation of physical and functional features of a facility. As of 2011, nearly half of the architecture, engineering, and construction sector was using BIM. It has been noted to have several benefits over traditional 2-D designs, such as in improving life-cycle management of buildings. Laser scanning technologies perform thousands of measurements per second of the 3-D coordinates of a designated area. The 3-D surface models created by these scans are much more accurate than traditional surveys. By combining BIM with laser scanning technologies, as-built conditions can be accurately captured and fully represented in the 3-D model, and updated as the project progresses. At project completion, the project site needs to be scanned and transferred to the as-built BIM file to assist with facility management (Randall 2011).

Another potential technology to be used for as-built development is Interactive Voice Response (IVR). A case example was performed to analyze the technology and suggest next steps to be taken in order to implement the technology in a larger dimension (Abdel-Monem and Hegazy 2013). The IVR system collected data about the project from supervisors on a daily basis or more frequently if initiated by the supervisor. The system calls the supervisors at the end of the workday and asks if any work has been completed. Based on the response of the supervisor, the system asks follow-up questions, such as the percentage of the expected daily work that was completed, and allows the supervisor to leave comments. The system will then send an e-mail to the project e-mail account with the information recorded during the phone call. Finally, a reporting tool will log all communication and update the schedule. For this case example, Ifbyphone, Microsoft Office, and Microsoft Project were used as the IVR system, e-mail tool, and scheduling tool, respectively. Individuals who participated in the case example stated the system was easy to use, had high sound quality, and was practical. However, they also mentioned the potential issues of the impact of construction noise on sound quality and there being less time to think about answers when being asked questions over the phone. This case example used the IVR system to track project progress; however, next steps of the project included adding as-built information, such as changes to materials and dimensions to the IVR system (Abdel-Monem and Hegazy 2013).

CHAPTER 3

Survey Results

This chapter provides information on current as-built methodologies in use at STAs and synthesizes the responses of the STAs about their current and future as-built development, preservation, and usage practices. This information was collected using a survey instrument developed by the study team with input from the oversight panel. The instrument was an electronic online survey developed using Qualtrics software. A copy of the survey instrument is included in Appendix A.

The focus areas include the following:

- Identification and description of current methodologies used to develop, preserve, and update as-built plans.
- Identification and description of the accuracy and usefulness of as-built plans.
- Description of as-built plan usage after approval.
- Identification of the limitations of current as-built plan methodologies as reported by STA survey respondents.
- Impact of alternative contracting methods on as-built development and usage.
- Identification of areas of improvement.

Survey Distribution and Responses

The survey questionnaire was distributed to voting members of the AASHTO Subcommittees on Design and Construction. The literature review conducted before the distribution of the survey was used to determine which AASHTO subcommittee member was most appropriate for each STA. If an STA's as-built information was located in design manuals, the voting member from the AASHTO Subcommittee on Design was contacted. If as-built information was found in construction manuals, the voting member from the AASHTO Subcommittee on Construction was contacted. If no as-built information was found, the voting member from Construction was contacted. Survey data were collected between February and March of 2019. Since some STAs' online manuals may not have been updated to describe the most current practice, information collected in the survey may differ from that of the online literatures. Responses were collected from 42 states for an 84% response rate, exceeding the minimum NCHRP standard response rate of 80%. Figure 5 depicts the geographical location of the respondents.

Definitions of As-Built Plans

Survey respondents were asked whether their agency has a documented definition of as-built plans. The STA survey results, Figure 6, indicate that 50% of respondents have a documented definition of construction as-built plans. Respondents were asked to provide

Figure 5. Geographic map of survey respondents.

the definition if their agency had one. Table 3 lists STA definitions of as-built plans provided by respondents.

Respondents were also asked if their agencies have a documented procedure for as-built development. Figure 7 shows that 68% of respondents have a documented procedure for as-built development. Of those, 75% provided their as-built development procedure.

Information Documented on As-Built Plans

The survey also sought to determine what information is being recorded on STA as-built plans. A multiple-choice question was asked of survey respondents about what information their STA requires to be documented on as-built plans. Preselected answer options were determined from the literature review conducted prior to the survey and input from the oversight panel. In addition, there was an option for the respondent to add items not offered as an answer. Results of the survey, Figure 8, indicate that the majority of STAs that answered the question require all changes made during construction to be documented on as-builts.

Three respondents provided additional information required to be documented on their as-built plans. The responses included the following:

- Electrical pull boxes and other electrical items,
- Minimum vertical clearances,
- Pavement lanes,
- Sidewalks,
- Islands,

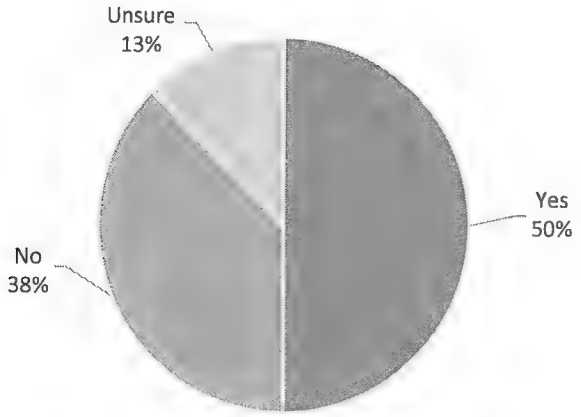


Figure 6. Documented definition of as-built plans.

- Median openings,
- Utility crosses,
- Irrigation crosses,
- Anything that could have an effect on future project development activities, and
- All corrections, repairs, revisions, and additional details necessary to depict the work as it was constructed.

Table 3. Definitions of as-built plans.

"The Record Plans consist of the original drawings on which all construction details which differ appreciably from the original design are shown in the color red. Record plans constitute the permanent record of exactly how the project was actually constructed for future reference and information."
"As-Built plans are the 'As-Awarded' project plan sheets that have been updated to reflect the changes, if any, which occurred during construction. As-Built plans represent the field conditions at the completion of the project."
"As-Built plans provide the permanent record of the actual structure and are used to develop plans for future work at the project site."
"This set of As-Built plans ... is intended to show approved revisions to the contract design including but not limited to: revised roadway profiles and cross sections, revised typical sections, revised drainage installations, any changes to the demolition and removal items and any other changes to the original design."
"The As-Built Plans are a compilation of the advertised Plan Sheets, Addendum Plan Sheets, Change of Plan (COP) sheets and other authorized changes."
"The 'as-built' drawings are an assembly containing a print or a PDF document of each original drawing, or revised sheet. Shop drawings may also be included with the plans if they provide any relevant information. 'As-Builts' are maintained for the purpose of recording approved field changes which are not shown on the drawings. Such field changes are usually of minor nature, as more significant changes usually require documented revisions to the plans."
"As-Built plans are a record of changes made to the originally intended physical product of the contract."
"Record Set shall consist of 8 ½" x 14" or 8 ½" x 11" reproductions of project drawings, plus the complete set of the project special provisions and standard special provisions."
"The Final As-Built Plans shall include all revisions and changes, both design and construction, that indicate precisely how the project was constructed."
"The field Record Plans will become the AS-BUILT PLANS when the project records are submitted to the Engineering Audit Section, and will be the permanent record of construction."
"As-Built plans will be completed with field notations describing changed conditions from the original design plans."

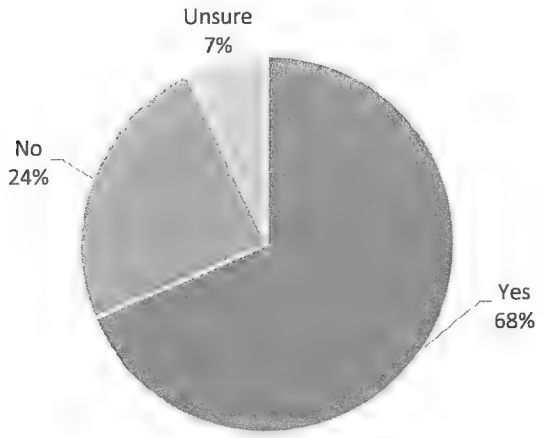


Figure 7. Documented as-built development procedure.

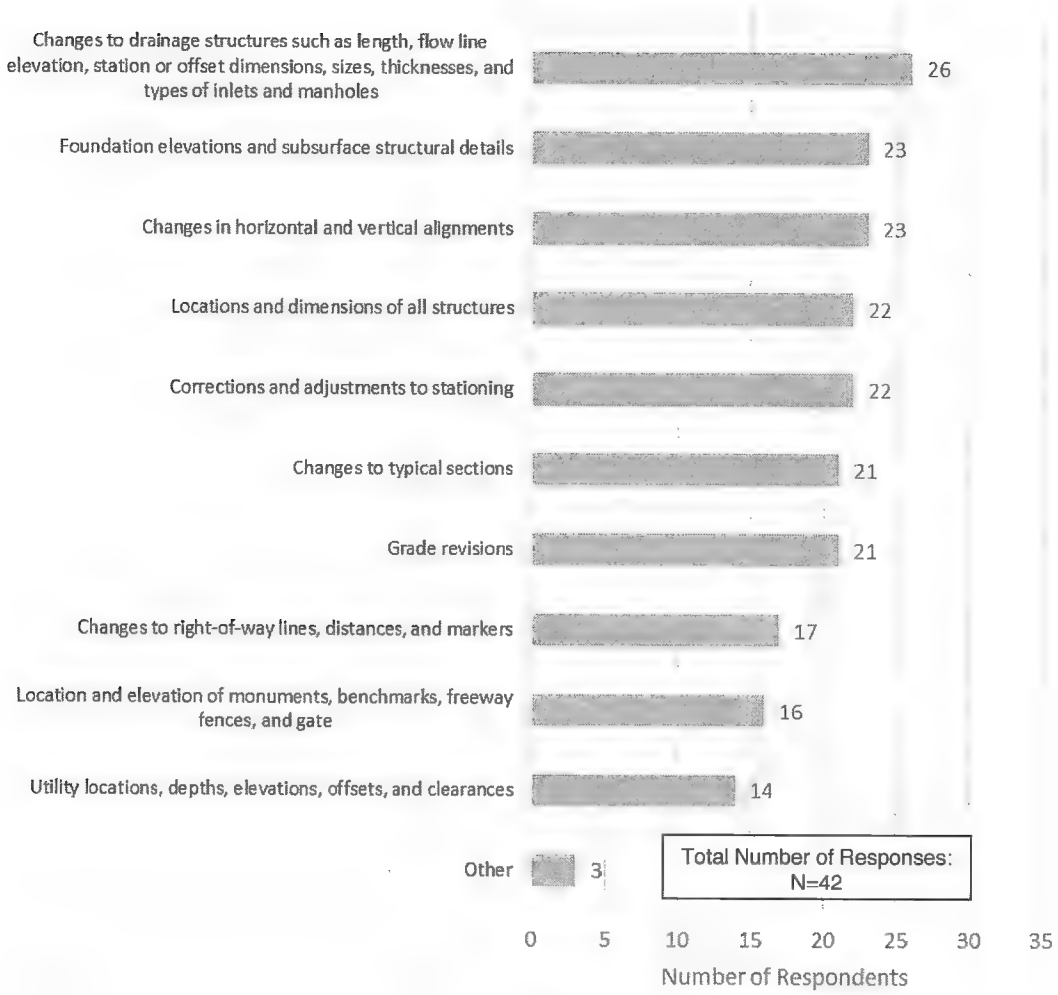


Figure 8. Information documented on as-built plans.

Methods Used to Capture and Document Changes During Construction

Another area of interest involves the methods used by STAs to capture and document changes made to the original project plans during construction. Respondents were asked to pick from a set of preselected methods developed from the literature review. Figure 9 illustrates survey responses.

Eighty-six percent (86%) of STAs indicated they are capturing and documenting as-built information by hand. This statistic is interesting, as the transportation industry has employed advanced technology over the past decades making project plans more accurate and with higher levels of detail, while it seems newer technologies have not been utilized to develop as-built plans. Survey respondents commented that handwritten notes are sometimes the most convenient and efficient way to record as-built information in practice. However, of the respondents who indicated they are recording as-built information by hand, 89% are also using other methods and technologies (Figure 10). This is an indication that, while the methods used for as-built development may be less advanced than that of original project plans, there is a movement to incorporate newer technologies.

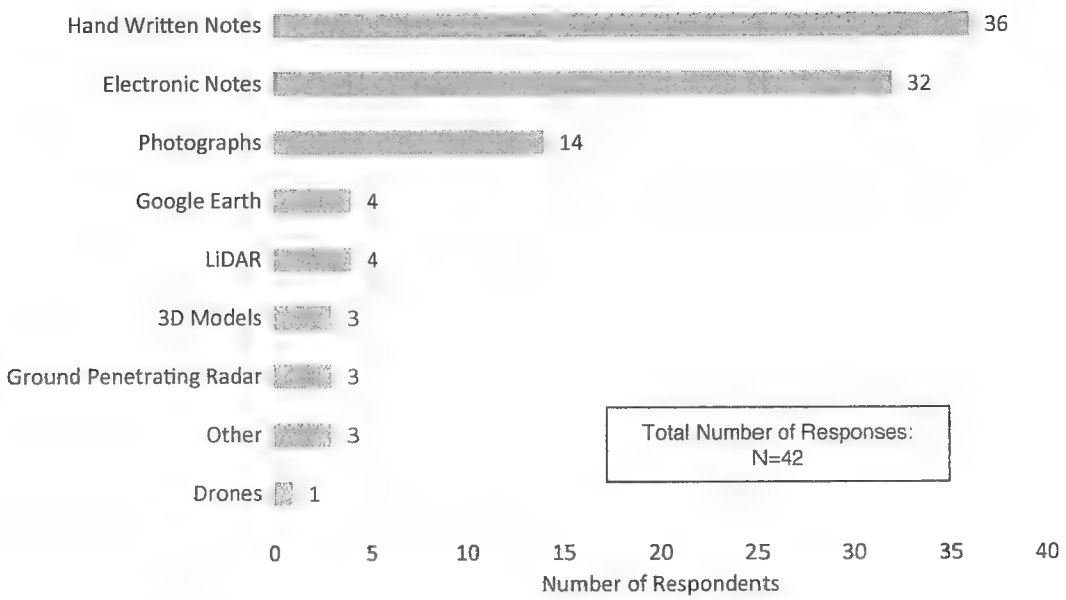


Figure 9. Methods used to capture and document changes.

Three STAs indicated they are using other methods to capture information than those listed previously. These other capture methods included contractor survey records, CAD files, and survey data files.

The survey also sought to determine if STAs were indicating the accuracy or quality of the as-built information they were capturing. Only one STA that responded to the survey indicated it assigns quality and/or accuracy levels to the as-built plans it develops to inform users of the degree to which the information was recorded. However, no information was provided on such quality and/or accuracy levels. This practice could increase the trust in as-built plans, as users would know to what degree the information provided was recorded.

Platforms Used to Establish As-Built Plans

The survey respondents were asked what platforms they use to establish as-built plans (Figure 11). The previous section describes how STAs are capturing and documenting changes in the field, and it is equally important to understand what technologies STAs are using to

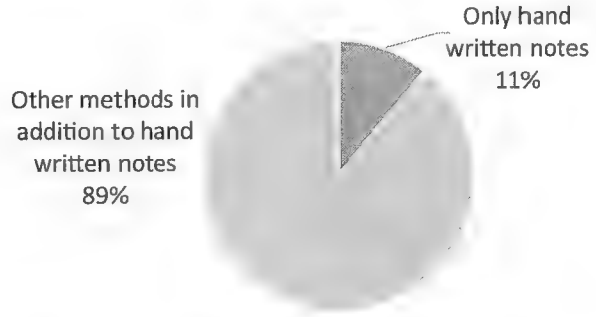


Figure 10. Methods used by STAs that indicated they capture as-built information by hand.

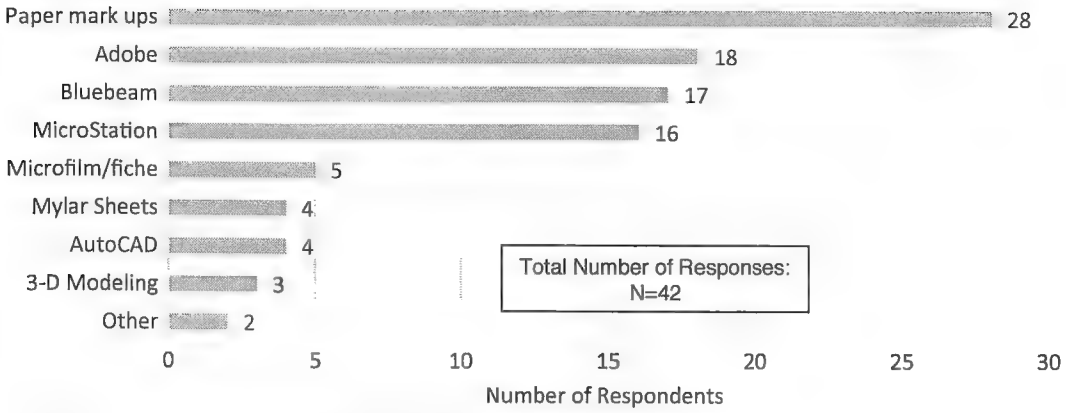


Figure 11. Platforms used to establish as-built plans.

establish the official plans. While an STA may capture as-built information in the field by hand-written notes, it may be using those notes to develop MicroStation as-built plans.

The majority of STAs are still establishing as-built plans as marked-up plan sheets. Similar to capture methods, the majority of STAs that still establish as-built plans this way also incorporate other platforms. Only 14% of respondents establish as-builts solely as paper plans (Figure 12).

The results of this survey question were interesting, considering the current technology of the industry. As expected, numerous STAs are establishing as-builts using PDF editors such as Adobe, Bluebeam, and CAD systems. However, five STAs indicated that they establish as-built plans as microfilm or microfiche, and only three indicated that they use 3-D modeling. Advanced technology has changed the accuracy and detail of project plans; however, it seems new technology has not had the same effect on as-built plans.

Entity Developing As-Built Plans

The survey also sought to determine which entity is responsible for as-built development. In-house employees such as construction and design employees, or outside entities such as design consultants or contractors, are all possible as-built developers. Figure 13 displays the percentage of respondents who indicated only in-house employees develop as-built plans, the percentage of respondents who employ in-house staff and outside entities to develop as-built plans, and the percentage of respondents who solely rely on outside entities to develop their as-built plans.

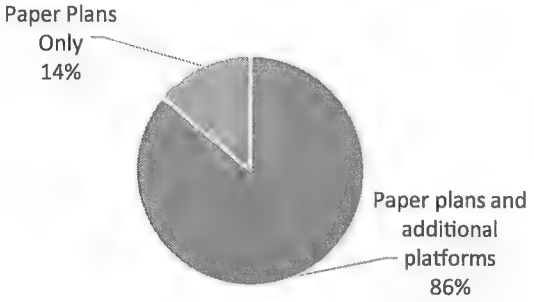


Figure 12. Platforms used by STAs that indicated they establish as-built plans as paper markups.

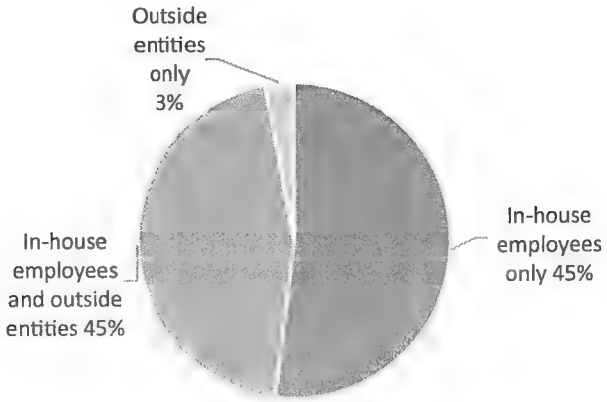


Figure 13. Entity responsible for as-built development.

While looking at which entity is responsible for as-built development, there was also information provided on what groups within the STA and which outside entities are developing as-built plans. Figures 14 and 15 show which specific groups are developing as-builts within and outside of the STA.

The majority of STAs are utilizing their construction groups to develop as-built plans, while seven have design groups involved in the process. Other responses included construction, engineering, and inspection (CEI) consultants, the Erosion Control Group, and the Bridge Program. Contractors and design consultants are also used by STAs to develop as-built plans. One STA is using a CEI consultant as the responsible party for as-built development.

Information on when these entities are developing as-built plans was also of interest. Respondents were asked when as-built development begins on the following scale: beginning of construction project, 25% project completion, 50% project completion, 75% project completion, and after the project is complete. Also, one respondent indicated that when as-built development begins varies project by project. Results are depicted in Figure 16. Most STAs are starting as-built development at the beginning of the project.

Approval of As-Built Plans

The survey sought to collect data on the approval process of as-built plans at STAs. First, respondents were asked if they have a documented procedure for as-built approval. If so, additional information was requested. Of the respondents, 39% indicated they have a documented as-built approval process (Figure 17).

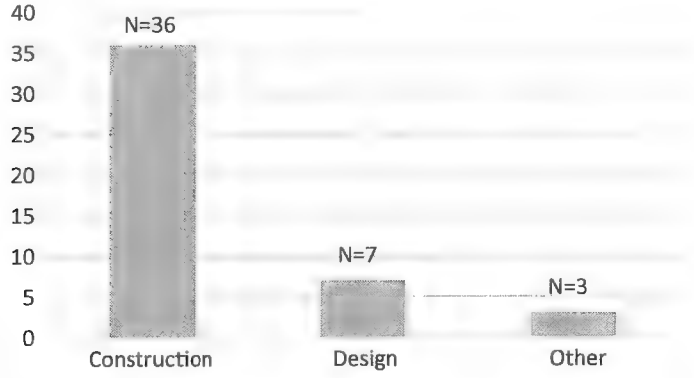


Figure 14. In-house groups developing as-built plan.

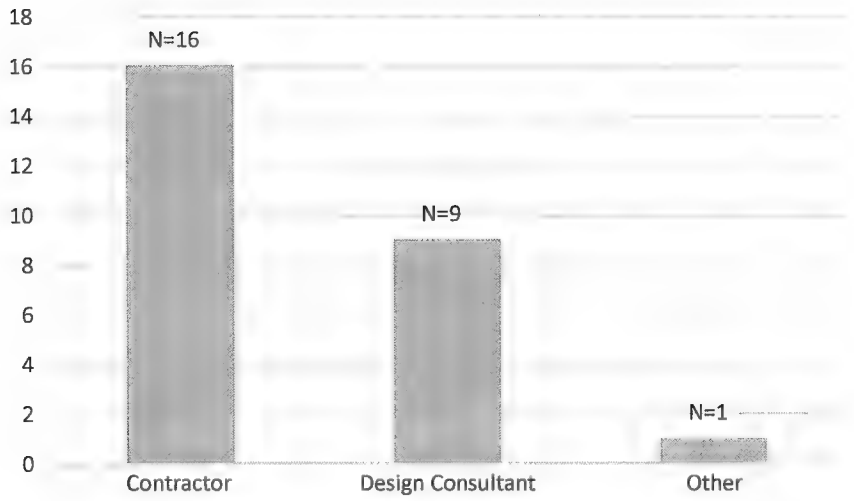


Figure 15. Outside entities developing as-built plans.

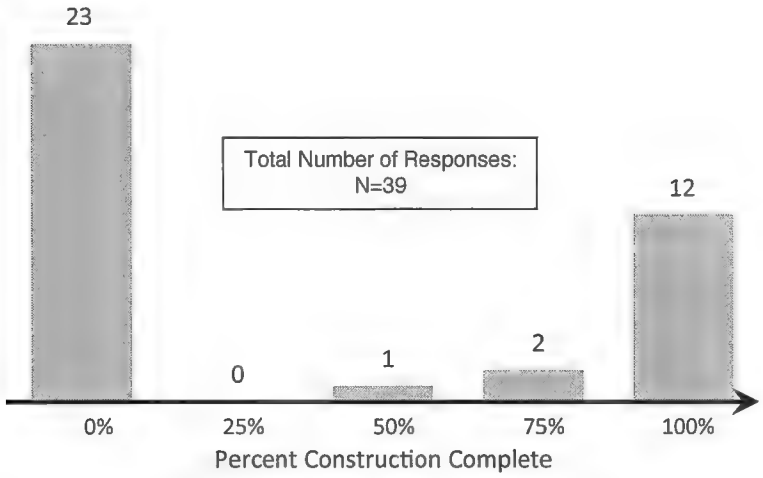


Figure 16. When as-built development begins.

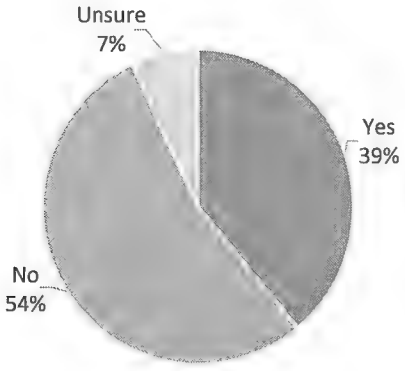


Figure 17. Documented as-built approval procedure.

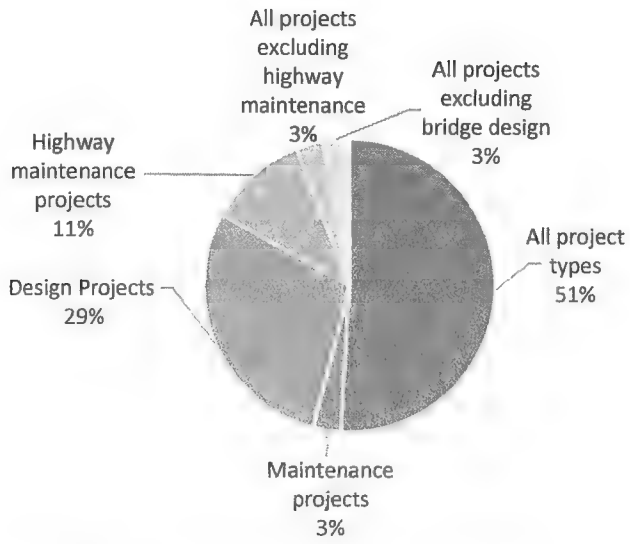


Figure 24. Project types that use approved as-built plans.

Next, how the agencies are using as-built plans was determined. Information of interest included which project types use approved as-built plans and what information from the plans is used. Figures 24 and 25 are graphical representations of the responses.

The majority of STAs indicated they are using as-built data for all project types. Twenty-nine percent (29%) use them for new highway and bridge design projects. One respondent indicated it uses them for maintenance only. Typical sections and alignments are the most frequently

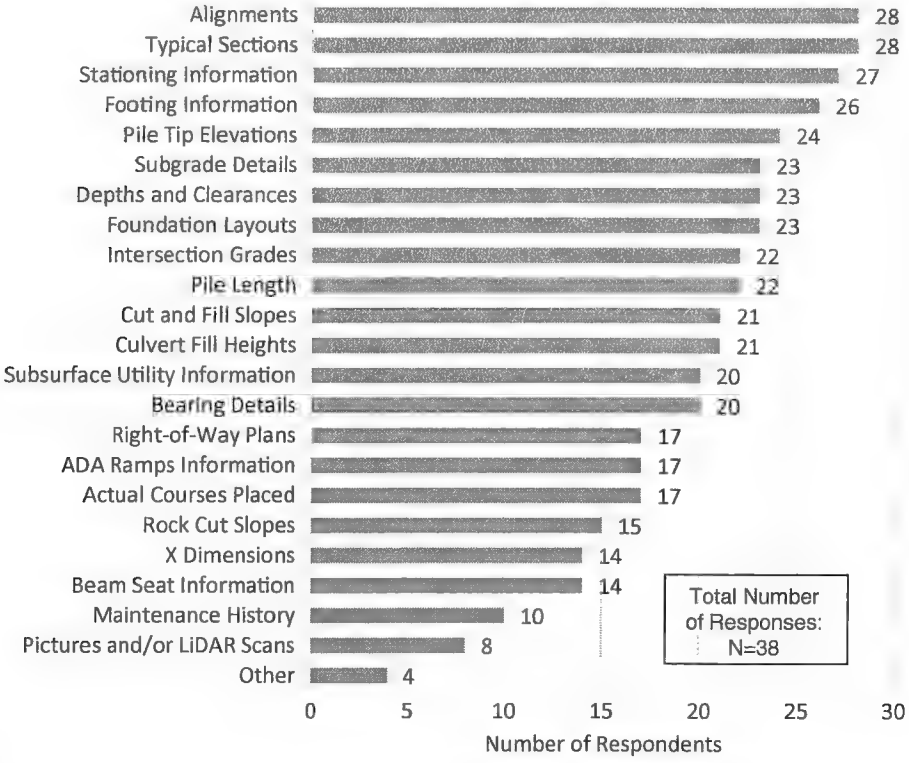


Figure 25. Information used from approved as-built plans.

used as-built information across respondents, while pictures and LiDAR scans of the site are less used. In addition to the responses depicted in Figure 25, one respondent noted it also uses elevation modifications and additions of minor structures from approved as-built plans.

As-Built Plans for Legal Purposes

When considering how as-built plans can be used in legal matters, who has access to the as-builts is relevant. From Figure 23, nine STAs indicated they provide access to their as-built plans to the general public and 20 provide access to other agencies besides their own. It is also important to consider whether as-builts are updated continuously. Only 11% of respondents indicated they updated as-builts for maintenance and additional work after the completion of initial construction.

It was decided that the storage and retrieval of as-built plans for legal purposes was too complicated for a survey question. For that reason, a case example was used to explore this topic. Arizona DOT indicated in its survey response that its Risk Management Department uses as-built plans. Its case example write-up found in Chapter 4 of this report goes into detail about how it uses as-built plans for legal purposes.

As-Built Information from Third-Party Agencies

As seen early in this chapter, STAs often rely on third-party agencies such as design consultants and CEI consultants to capture and record as-built information. This synthesis sought to determine how this information is transferred from these agencies to the STA. Figure 13 shows that 48% of respondents utilize third-party agencies to assist in as-built development. The survey itself did not explore the topic of how this information is transferred between the third-party agency and the STA itself. However, six case examples can be found in Chapter 4 of this report in which this topic was thoroughly discussed.

Of the six STAs in which this question was asked, e-mail was the most common response to how they receive as-built information from third-party agencies. USB and disc storage were also cited as ways to obtain the information.

How Project Delivery Methods Affect As-Built Plans

One question was present in the survey to determine if STAs employ different as-built procedures according to the project delivery method. This information was used in the selection of STAs to participate in a case example. Fifty-five percent (55%) of respondents indicated the entity responsible for as-built development varied by delivery method (Figure 26). Two of the six STAs interviewed for the case studies indicated the entity responsible for as-built development varied based on delivery method. Differences in as-built procedures by delivery method were further examined in case examples.

Issues and Future Improvements to As-Built Procedures

Four survey questions were asked to respondents in regard to current issues they face with as-built procedures and future opportunities for improvement. Respondents were first asked what they see as necessary improvements to their current as-built procedures (Figure 27). Accessibility to the public and loosely defined as-built procedures were additional written responses.

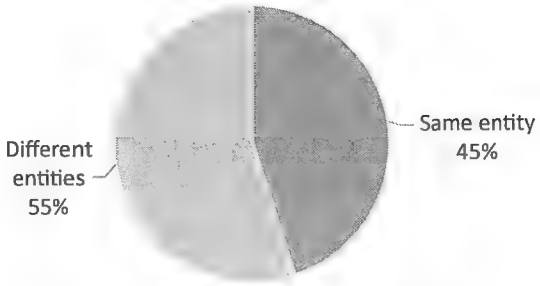


Figure 26. Effect of project delivery method on entity responsible for as-built development.

Follow-up questions were asked about whether the agency plans to or has already begun to refine its current as-built procedures and, if so, which aspect of its procedure it plans to refine. Eighteen (18) respondents indicated they planned to or are beginning to refine their current as-built procedures. When asked what aspects of the procedures they plan to refine, all but one indicated they planned to refine or improve the method used to capture as-built information. Improving this aspect of as-built development should improve the accuracy and usability of as-built plans as well as improve efficiency in as-built collection. This also has the potential to incorporate new technology available in the industry. Aspects of as-built procedures these 18 respondents plan to refine are shown in Figure 28. Written responses recorded as "Other" included exploring electronic document possibilities such as Bluebeam and 3-D models, requirements for 3-D models, the retrieval process, and public publication.

Finally, respondents were asked what key challenges they face when attempting to improve as-built procedures (Figure 29). STAs may benefit from understanding and addressing the challenges they and other STAs face while attempting to improve and refine as-built procedures. More than half of the responding STAs indicated they lack the technical staff to improve the current as-built procedures, 32% are experiencing IT issues and a lack of technology, 26% are uncertain where to begin their improvement process, and 6% lack management support. Other written-in responses included available time, personnel training, resource issues, record retention policies, the culture of paper versus electronic plans, and deciding on which technology to use and where to store as-builts to maximize the awareness of the existing as-builts.

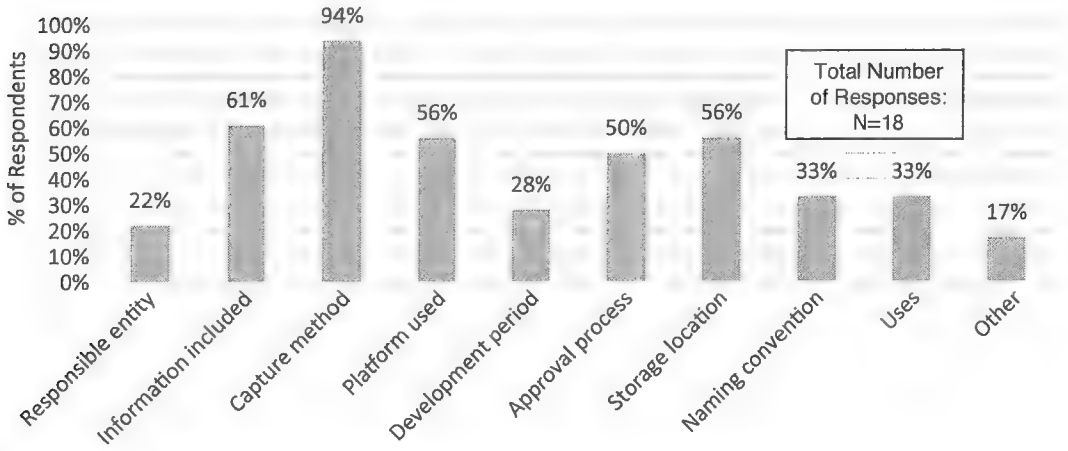


Figure 27. Necessary improvements to current as-built procedures.

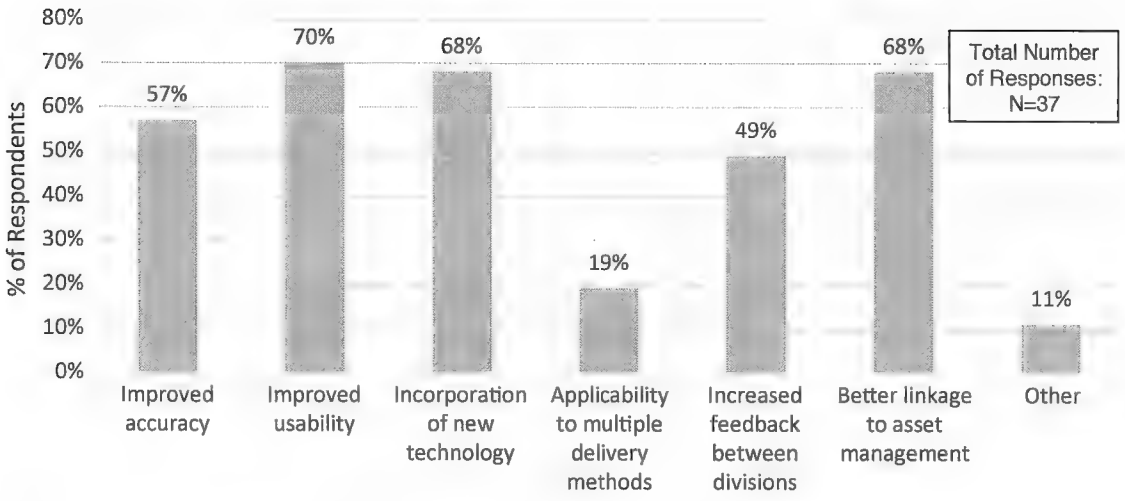


Figure 28. Aspects of as-built procedures that STAs are refining.

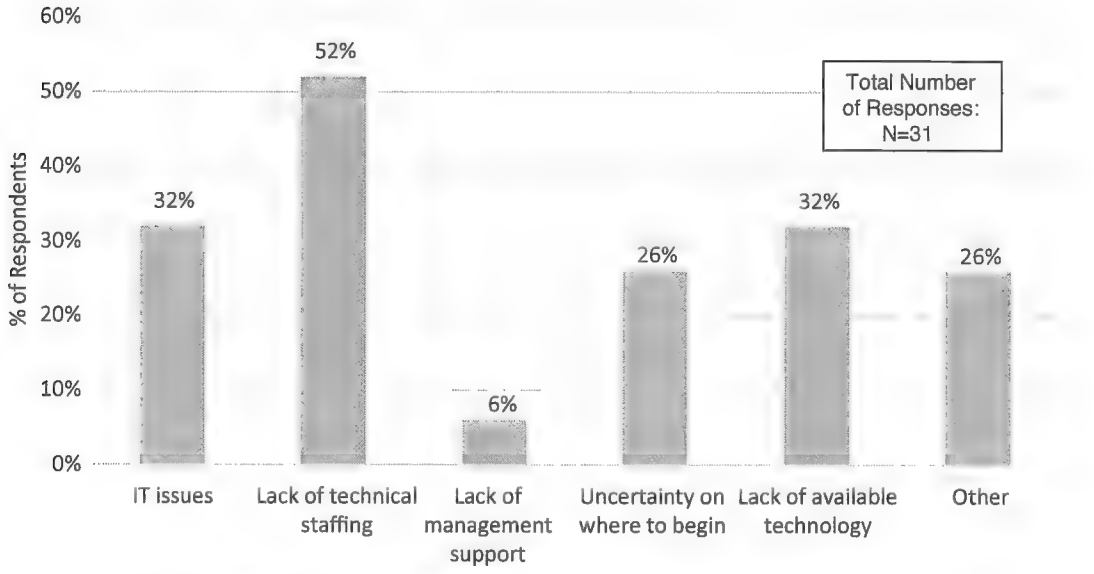


Figure 29. Challenges faced in making improvements to as-built procedures.

CHAPTER 4

Case Examples

This chapter of the report describes the STA case examples that were based on the initial survey results. The follow-up interviews will help other STAs enhance or improve their current as-built procedures. The states selected for these interviews/case examples were Arizona, Colorado, Kentucky, Minnesota, Virginia, and Wisconsin. The interviews were conducted using Zoom web conferencing. The topics of the conversation centered on the following points:

- Specific as-built development, preservation, and renewal methods;
- Accuracy and usefulness of completed as-built plans;
- Who is using as-built plans after their approval;
- How as-built plans are used after their approval;
- Impact of alternative delivery methods on as-built plans;
- Lessons learned on as-built plan development, preservation, usage, and renewal; and
- Impact of as-built plans on project performance measures.

The interview candidates were selected for the following reasons, in approximate order of precedence:

1. STAs indicating they were willing to be interviewed.
2. STAs that have well-defined as-built procedures.
3. STAs viewed as progressive in as-built development.
4. STAs viewed as progressive in as-built storage and preservation.
5. STAs viewed as progressive in as-built usage.
6. STAs that employ different as-built procedures according to project delivery method.
7. STAs with varying sizes, complexities, and regional locations.

Arizona

As-Built Procedure Best Practices and Implemented Research

The Arizona Department of Transportation developed an as-built web page that has significantly improved as-built procedures. Everything regarding Arizona DOT as-built procedures can be found on this page. The web page includes frequently asked questions, common mistakes in preparing record drawings, record-drawing guidelines, record-drawing examples, a record-drawing process flowchart, contact information, the link to completed as-built plans, and additional resources.

Figure 30 shows the list of frequently asked questions regarding record drawings found on Arizona DOT's as-built web page, and Figure 31 shows the list of common mistakes in preparing record drawings.

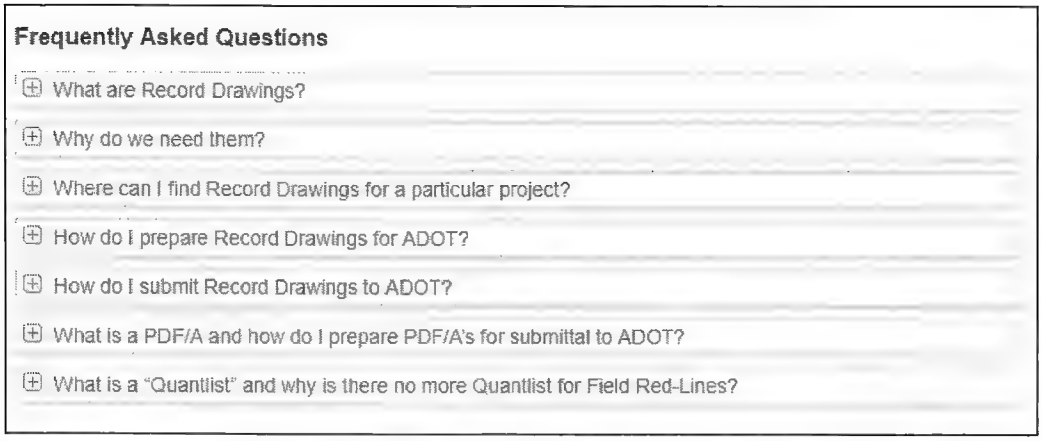


Figure 30. Frequently asked questions regarding record drawings on Arizona DOT as-built web page.

According to Arizona DOT, the record-drawing process flowchart is one of the most useful aspects of the web page. It provides a step-by-step procedure on how record drawings should be developed and stored. The flowchart is depicted in Figure 32.

The resident engineer is responsible for developing the redline plans in the field. These redlines are sent to the record drawing designer, who uses them to create the PDF record drawings. Record drawings go through several checks at Arizona DOT, and the resident engineer must approve the record drawings developed by the designer. The approved record drawings must be e-mailed to the Project Resource Office (PRO) along with the Record Drawing Project Submittal Form. PRO will check the record drawings for compliance, and if all guidelines are met the record drawings will be uploaded to the Repository of Online Archived Documents (ROAD). These drawings are available in the Arizona DOT Information Data Warehouse (AIDW). A link to ROAD can be found on the Arizona DOT as-built web page. Before the final payment can be delivered and the project can be closed out, as-built plans must be in-house and approved.

ROAD is available to the public, and record drawings can be found using the record-drawing search tab. Figure 33 depicts the record-drawing search feature in ROAD.

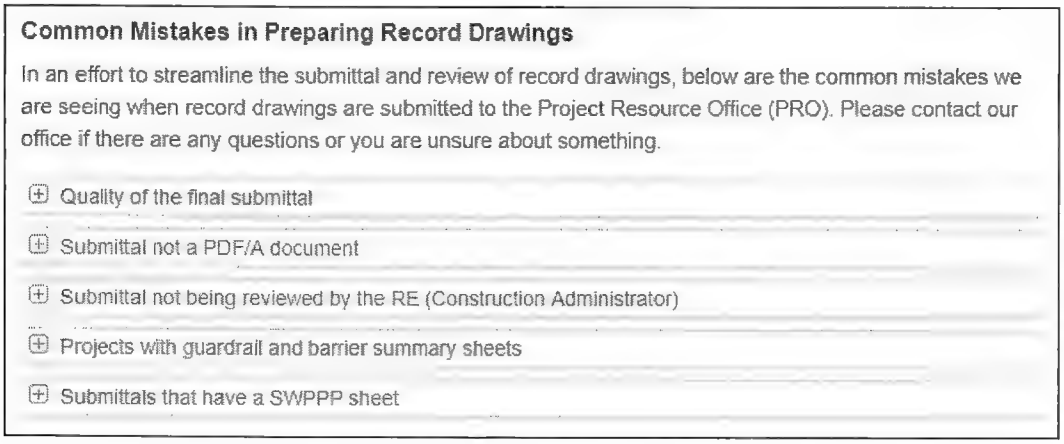


Figure 31. Common mistakes in preparing record drawings on Arizona DOT as-built web page. SWPPP = Stormwater Pollution Prevention Plan.

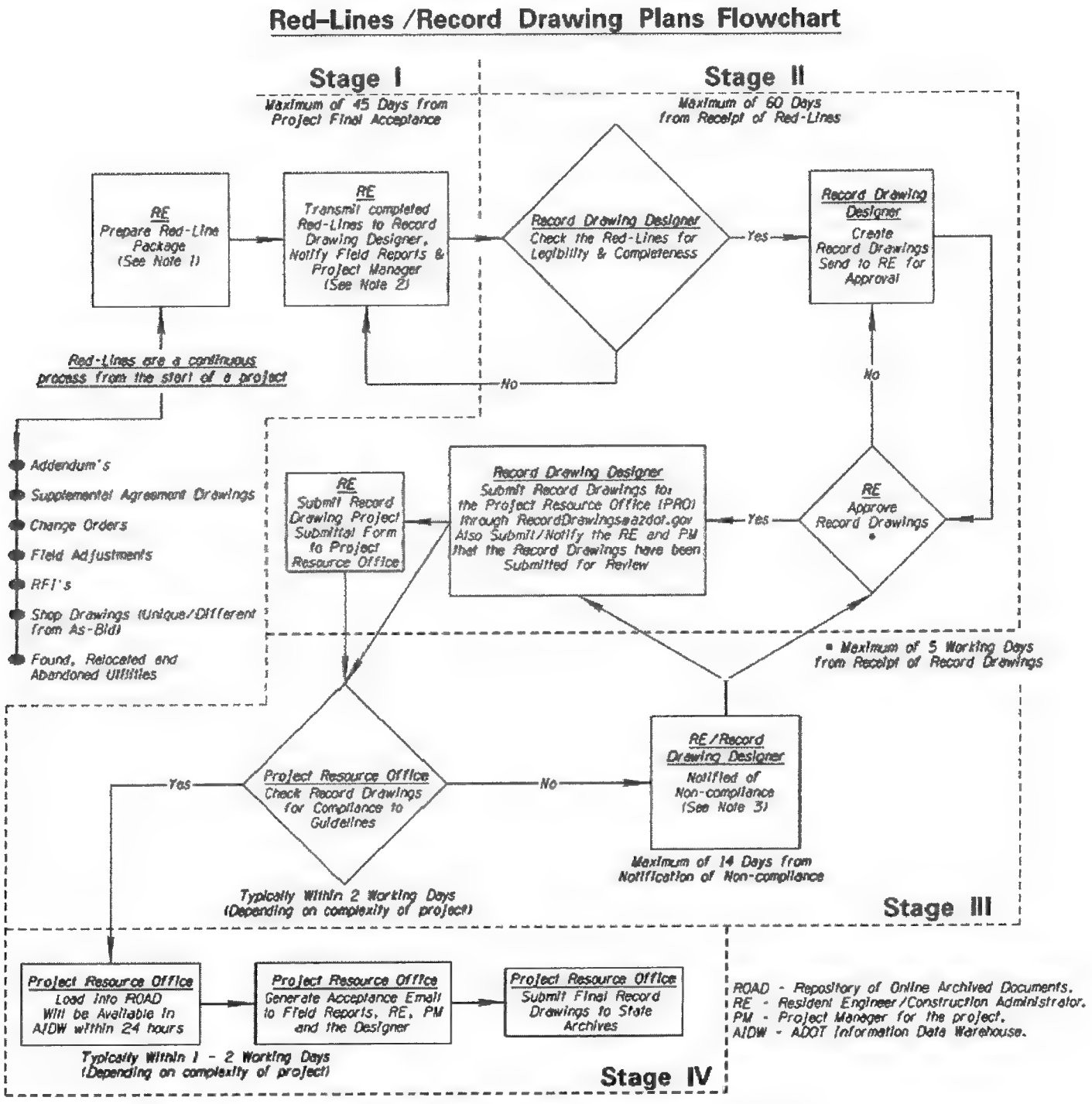


Figure 32. Stages I and II of Arizona DOT's redlines/record-drawing plans flowchart.

Figure 33. Record-drawing search in ROAD.

Arizona DOT is also making progress in the transparency of as-built plans. Arizona DOT encourages the public to get information on transportation infrastructure through ROAD. This transparency inevitably requires litigation involvement under some circumstances. If a project is under construction or has been completed but the record drawings have not yet been uploaded to ROAD, the public must go through the Risk Management Office. Risk Management will determine whether the information can be released.

Varying As-Built Procedures According to Project Delivery Method

As-built procedures are generally the same for all project delivery methods. However, the entity responsible for as-built development may vary from project to project. The project manager, with input from the project team, decides who is responsible for as-builts for a project. For simple projects, often design–bid–build projects, districts are responsible for as-builts; however, for more complex projects or design–build projects, a consultant or the design–builder is responsible for as-built development. The designer responsible for the official record drawings is dependent on the type of project. For example, a traffic designer would be the record-drawing designer for a traffic project.

As-Built Information on Warranties, Agreements, and Deployed Technology

Arizona DOT does not collect information on warranties or agreements. Information on deployed technology is not included in the as-built plans and is sent to Homeland Security in the district office separately.

Incorporation of As-Built Data into Asset Management

As-built data are not currently incorporated into asset management. When as-built data are needed, that information must be pulled from the as-built plans. Arizona DOT would eventually like to incorporate as-built data into asset management to get the most accurate information available.

As-Built Information Received from Third-Party Agencies

Third-party agencies can share record drawings in one of two ways. Record drawings can be e-mailed directly to Arizona DOT as PDFs, or as a link to the record drawings from the company site or file-sharing site. If a link is shared, the files must be available for download for 14 days.

Colorado

As-Built Procedure Best Practices and Implemented Research

Colorado Department of Transportation also has a specification regarding as-built plans or, as Colorado DOT refers to them, construction drawings. Figure 34 is Colorado DOT Specification 105.02 (f). According to the spec, the contractor is responsible for construction drawings that are submitted to the engineer before the final payment. These drawings should be maintained as the project progresses, and notations on the drawings must be made within seven days of the change. The construction drawings completed by the contractor are used to develop the as-constructed plans. Official as-constructed plans are developed using MicroStation or Redline Software if the plan set is prepared electronically. Colorado DOT stated that electronic plans help with the as-built process because they are easier to prepare and maintain.

Colorado DOT's construction manual lists specific information to be incorporated into the as-constructed plans. As-constructed plans should contain a professional engineer's stamp; changes to the scope of work, intent of contract, geometric design, structural plans, typical sections, standard plans, and specifications; and corrections to design errors. The construction manual also contains detailed procedures for preparing electronic and manual as-construction plans.

Varying As-Built Procedures According to Project Delivery Method

In general, as-built procedures do not vary by project delivery method at Colorado DOT. The contractor is always responsible for construction drawings, and the project engineer receives those plans and oversees the transformation of those plans to the as-constructed plans. However, contracts for design–build projects have a different language than other delivery methods. At Colorado DOT, contractors are more likely to complete the construction drawings on time and properly on design–build projects.

Specification

105.02 (f) *Construction Drawings.* The Contractor shall keep one set of plans, reviewed shop drawings, working drawings, and other submittals available on the project site at all times. This set shall be defined as the "construction drawings." The Contractor shall note on these construction drawings all changes and deviations from the work shown on the plans, shop drawings, working drawings, and other submittals. The construction drawings shall be kept current as the work progresses and notations shall be made within seven days of the change or deviation.

The first sheet or page of each set of construction drawings shall be stamped "As Constructed" and signed by the Contractor.

Upon completion of the work and prior to final payment, the construction drawings shall be submitted to the Engineer.

Figure 34. Colorado DOT Specification 105.02 (f).

As-Built Information on Warranties, Agreements, and Deployed Technology

Colorado DOT does not perform projects with warranties. Its contracts for projects with agreements or deployed technology are the same as all contracts; therefore, as-built development does not differ for these projects.

Incorporation of As-Built Data into Asset Management

Colorado DOT is incorporating as-built data into signal and bridge assets. Signal inventory and asset condition data are maintained statewide and are updated to show new or replaced signals; however, specific as-builts are not referenced in the inventory.

Bridge asset management recommendations aim to incorporate the history of all structures. The majority of Colorado DOT's structures' as-builts are located on e-folders that allow for easy access. A goal for Colorado DOT is to locate and provide as-built plans for the entire structure asset inventory in the e-folders. Asset management recommendations rely on the current condition, and as-built plans are beneficial when evaluating projects and potential treatments. As-builts incorporated into asset management are extremely helpful from this standpoint.

As-Built Information Received from Third-Party Agencies

Colorado DOT allows as-builts to be delivered as hard-copy plans or electronic plans. There is no requirement for how these plans are shared. Electronic plans are often shared in e-mails, as CDs, or through USB flash drives.

Kentucky

As-Built Procedure Best Practices and Implemented Research

Currently at the Kentucky Transportation Cabinet (KYTC), as-built plans are developed by construction personnel by hand or using editing software on iPads. These plans are then stored in ProjectWise as PDFs. However, KYTC has an ongoing research project on improving the as-built process (KYSPR-18-555, *Redefining Construction "As-Built" Plans to Meet Current KYTC Needs*). Interviews were conducted with Project Development (i.e., as-built end users) and Project Delivery (i.e., as-built developers) to identify potential improvements to current as-built procedures.

An as-built checklist was developed that provides as-built information requested by end users at KYTC to as-built developers and the minimum acceptable recording method (Tables 5 and 6).

The checklist provides the as-built information needed for each category of end users (Table 5). It also describes the minimum acceptable recording method for required as-built information. Table 6 is a checklist of necessary as-built information broken down according to work type. Projects with these work items require as-built information. All as-built information is converted to PDF format before its submission.

The minimum acceptable recording method ensures the information collected is done so in a way that the information will be useful to end users. When the as-builts are developed was also of interest within the research. According to KYTC as-built developers, developing as-builts throughout the project as it progresses is the most efficient way to develop these plans.

In addition to the as-built checklist, KYTC indicated it had an as-built point of contact at KYTC to enhance the as-built process. This point of contact would be responsible for uploading

Table 5. Kentucky Transportation Cabinet as-built checklist.

End User	Required As-Built Information	Minimum Acceptable Recording Method
Bridge Maintenance	Pile tip elevations	Hand-drawn
	Concrete cylinder breaks	Hand-drawn
	Beam seat information	Hand-drawn
	X-dimensions	Hand-drawn
	Culvert fill heights	Hand-drawn
	Foundation layouts	Hand-drawn
Pavement Design	Actual courses placed	Hand-drawn
	Typical sections	Hand-drawn
	Subgrade details	Hand-drawn
	American with Disabilities Act (ADA) ramp information	App
	Intersection grades	Mobile LiDAR
Highway Design	Anything underground	Hand-drawn
	Alignments	Hand-drawn
	Picture of completed project	Camera
	LiDAR scan of completed project	Mobile LiDAR
Structural Design/Geotechnical	Footing information	Hand-drawn
	Pile lengths	Hand-drawn
	Stationing equations for where bridges and roads meet	Hand-drawn
	Changes in bridge length	Hand-drawn
	Piers built at wrong skew	Hand-drawn
	Bearing details	Hand-drawn
	Rock cut slopes	Drone
	Cut and fill slopes	Hand-drawn
Utilities	Subsurface utility information	Hand-drawn
	Utility conflict information	Hand-drawn
	Alignments	Hand-drawn
	Depths	Hand-drawn
	Clearances	Hand-drawn
Permits	Permitted facilities	Hand-drawn

as-built plans to the appropriate destination and ensuring they are being completed consistently and uniformly.

Varying As-Built Procedures According to Project Delivery Method

As-built plans are developed by construction personnel at KYTC. However, under most circumstances for design–build projects, the design–builder is responsible for developing the as-built plans. During interviews with as-built developers, it was suggested that outside entities such as design consultants or contractors be employed to assist with as-built plan development, depending on the project. Besides the case of the design–builder creating as-builts for design–build projects, there is no variation in as-built procedures according to delivery method.

As-Built Information on Warranties, Agreements, and Deployed Technology

It was of interest if STAs record specific or different as-built information on projects with warranties, agreements, or deployed technology. KYTC does not differentiate such projects in regard to as-builts, and as-built information recorded is the same.

Table 6. Kentucky Transportation Cabinet as-built information by work type.

Major Work Product	Work Product Components	Individual Work Items	Required As-Built Information	Collection & Recording Method (Current Recommendation)	Future Collection & Recording Methods
Structures			• Concrete Cylinder Breaks	• Test and Record in SiteManager	
	Foundation	Piles	• Pile Tip Elevation/Lengths • Measured Bearing	• Direct Measure and Record on Pile Logs	
		Foundation Layout	• Bottom of Footer Elevation	• Direct Measure and Record on Plans	
	Substructure	Abutment/End Bent	• Beam Seat Elevations • Beam Seat Layout • Wing Wall Dimensions	• Direct Measure and Record on Plans	
		Piers	• Beam Seat Elevations • Beam Seat Layout	• Direct Measure and Record on Plans	
	Superstructure	Bridge Deck	• X-Dimensions • Finished Grade	• Surveyed and Record as PDF • Direct Measure and Record on Plans	
	Culvert		• Culvert Fill Heights • Wing Wall Dimensions	• Direct Measure and Record on Plans	
		Foundation Layout	• Bottom of Footer Elevations	• Surveyed and Record as PDF	
Roadway		Right of Way Completed Project	• Actual Roadway Monuments and Lines	• Survey and Record on Plans • Picture & GPS and Record on ArcGIS	• Google Earth
	Subgrade	Stabilization Method	• Cement/Line/Rock Roadbed	• Record Method Used as PDF	
	Asphalt/ Concrete Pavement	Base Courses	• Actual Courses and Thickness	• Direct Measure and Record on Plans	
Permitted Facilities		Entrances	• Permitted Facilities • Scaled Drawings	• Visual Inspection and Record on Plans	• GPS/Geographic Information System (GIS) Asset Management System • PDF Redline Editor
Utilities		Underground Utilities	• Subsurface Information • Conflict Information	• Measured or Surveyed and Record on Plans • Record in	• As per ASCE 38-02 • As per SHRP 2 R01A
			• Alignments, Depths, and Clearances	Maintenance Database	• GPS/Asset Management

Incorporation of As-Built Data into Asset Management

Currently, as-built data are not being incorporated into asset management and little discussion on asset management was present in interviews. However, as research on as-built procedures continues at KYTC, this is an area for consideration and enhancement.

As-Built Information Received from Third-Party Agencies

As-built plans are developed by construction personnel at KYTC. However, when a third-party agency provides as-built information, it is typically shared by e-mail.

Minnesota

As-Built Procedure Best Practices and Implemented Research

The Minnesota Department of Transportation has taken enormous steps in as-built development. The following timeline shows the progression of its as-built procedures since 2009.

- 2009—Learned about the process
- 2010—Metro District As-Built Committee was formed
- 2011—Created a uniform as-built pay item/specification that included five asset classes
- 2012—Metro District initiated four pilot projects
- 2015—Implementation to all Metro District projects
- 2017—Greater MN District meetings were held
- 2017—Added six assets and updated as-built specifications
- 2018—District tour
- 2019—Statewide As-Built Committee was formed

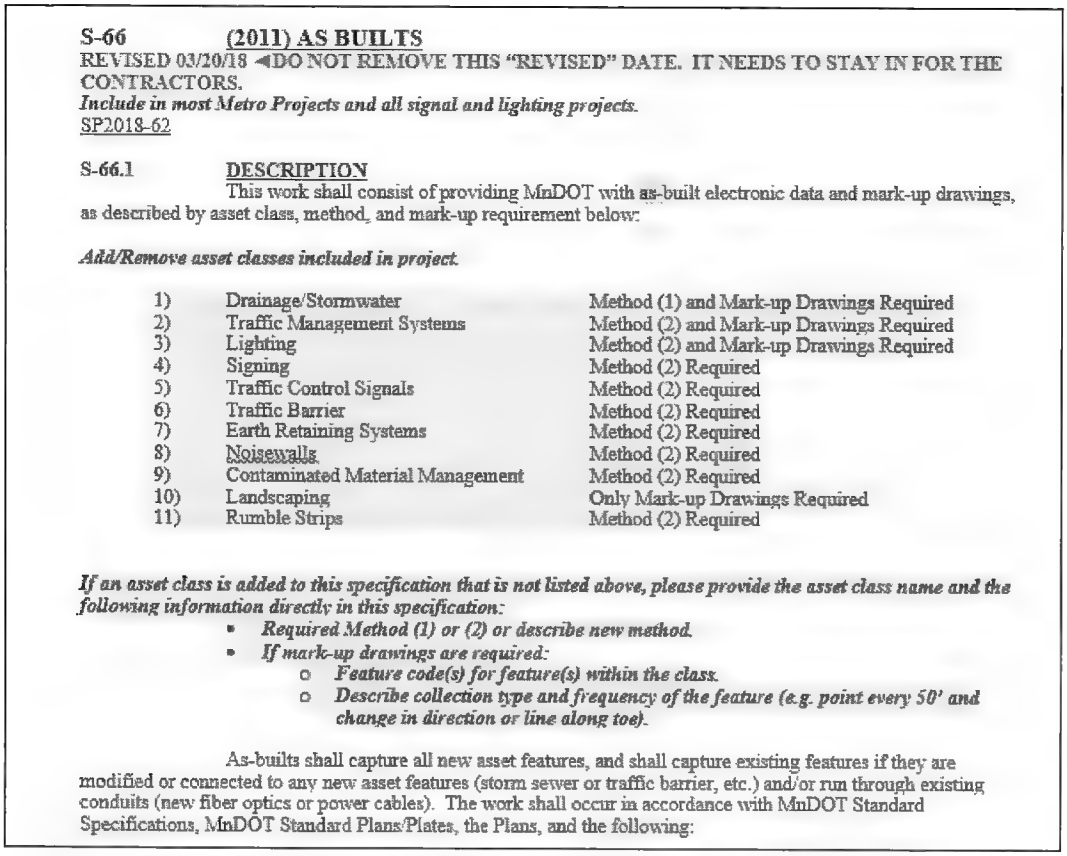
Through this process, Minnesota DOT discovered the key factors to a successful as-built program are leadership support, ownership, clear communication, clear business process, and data value through system integration.

The as-built information collected at Minnesota DOT includes asset type and feature, geospatial geometry, and asset inventory attributes, which are established as Excel (.csv) files or shapefiles and marked-up drawings established as PDF files. The asset information is divided into 12 asset classes and is listed in the Minnesota DOT 2011.601 As-Built Specification and Pay Item. Figure 35 is Specification and Pay Item 2011.601.

This pay item/specification accurately tracks costs and allows for payment to be held until as-built plans are completed and submitted. Methods 1 and 2 listed in the spec are methods in which the information must be collected and indicate required accuracy. As-builts must be e-mailed by the contractor to the project engineer while copying Minnesota DOT's as-built e-mail address.

Minnesota DOT has also developed an as-built website to assist with as-built development. The website has tabs for the asset classes. Each tab contains the specific features to be collected; feature codes; GPS location requirements; an electronic spreadsheet that includes field names, metadata, and example collection data; and a key contact for that asset class. As an example, Figure 36 shows the Traffic Barriers page of the as-built website.

Once the as-built information is submitted in the formats mentioned previously, the data are entered into the Transportation Asset Management System (TAMS), which focuses on asset inventory and performance and maintenance management. This system is integrated with Esri Roads and Highways, Swift, and the ArcGIS server for viewing.



S-66 (2011) AS BUILTS

REVISED 03/20/18 ◄DO NOT REMOVE THIS "REVISED" DATE. IT NEEDS TO STAY IN FOR THE CONTRACTORS.

Include in most Metro Projects and all signal and lighting projects.

SP2018-62

S-66.1 DESCRIPTION

This work shall consist of providing MnDOT with as-built electronic data and mark-up drawings, as described by asset class, method, and mark-up requirement below:

Add/Remove asset classes included in project.

1)	Drainage/Stormwater	Method (1) and Mark-up Drawings Required
2)	Traffic Management Systems	Method (2) and Mark-up Drawings Required
3)	Lighting	Method (2) and Mark-up Drawings Required
4)	Signing	Method (2) Required
5)	Traffic Control Signals	Method (2) Required
6)	Traffic Barrier	Method (2) Required
7)	Earth Retaining Systems	Method (2) Required
8)	Noisewalls	Method (2) Required
9)	Contaminated Material Management	Method (2) Required
10)	Landscaping	Only Mark-up Drawings Required
11)	Rumble Strips	Method (2) Required

If an asset class is added to this specification that is not listed above, please provide the asset class name and the following information directly in this specification:

- ***Required Method (1) or (2) or describe new method.***
- ***If mark-up drawings are required:***
  - ***Feature code(s) for feature(s) within the class.***
  - ***Describe collection type and frequency of the feature (e.g. point every 50' and change in direction or line along toe).***

As-builts shall capture all new asset features, and shall capture existing features if they are modified or connected to any new asset features (storm sewer or traffic barrier, etc.) and/or run through existing conduits (new fiber optics or power cables). The work shall occur in accordance with MnDOT Standard Specifications, MnDOT Standard Plans/Plates, the Plans, and the following:

Figure 35. Minnesota DOT 2011.601 As-Built Specification and Pay Item.

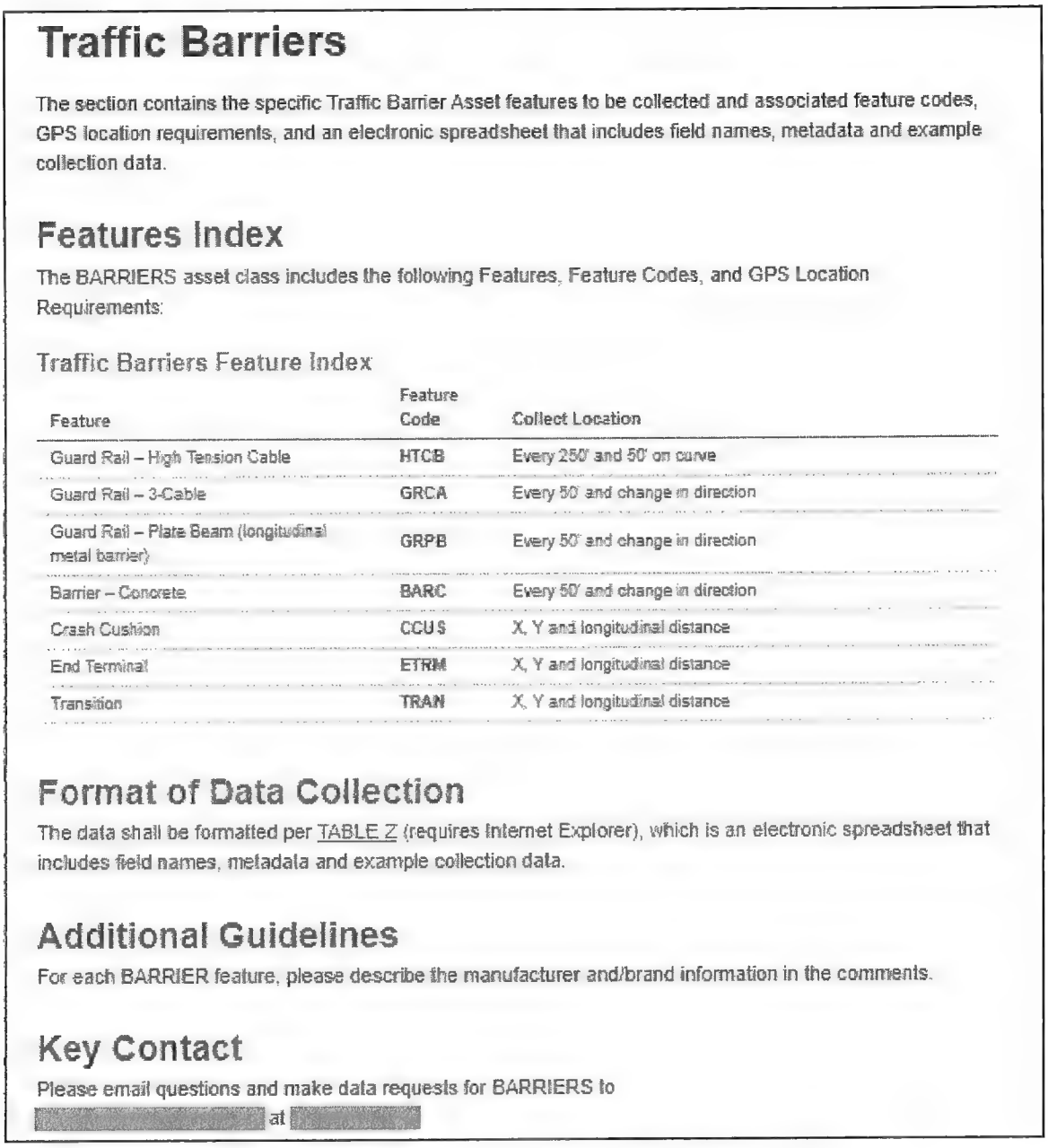
Currently, Minnesota DOT is tracking let construction projects and as-built usage, communicating District 2018 projects and the status of the data, conducting monthly statewide as-built working group meetings, and compiling special provisions/website changes. Next steps include a case example on utilizing as-built data, adding asset classes to 2011.601, continuing to build contractors' expertise, and improving the business process.

Varying As-Built Procedures According to Project Delivery Method

The as-built procedure at Minnesota DOT is a newly defined procedure. Currently, only one process exists for all delivery methods and is the process outline described earlier, but not all projects require as-builts. However, Minnesota DOT indicated that as progress continues research on improvements will continue. While there was no direct mention of differing procedures according to delivery method, Minnesota DOT mentioned it can begin to compare as-built collection methods, such as who the responsible party is for as-built development.

As-Built Information on Warranties, Agreements, and Deployed Technology

Minnesota DOT does not alter its as-built collection methods for projects with warranties, agreements, or deployed technology. It indicated that such information could be an attribute of an asset in TAMS. Currently in TAMS, manufacturer information is an asset attribute; however, as-built specifications do not ask for this information.



Traffic Barriers

The section contains the specific Traffic Barrier Asset features to be collected and associated feature codes, GPS location requirements, and an electronic spreadsheet that includes field names, metadata and example collection data.

Features Index

The BARRIERS asset class includes the following Features, Feature Codes, and GPS Location Requirements:

Traffic Barriers Feature Index

Feature	Feature Code	Collect Location
Guard Rail – High Tension Cable	HTCB	Every 250' and 50' on curve
Guard Rail – 3-Cable	GRCA	Every 50' and change in direction
Guard Rail – Plate Beam (longitudinal metal barrier)	GRPB	Every 50' and change in direction
Barrier – Concrete	BARC	Every 50' and change in direction
Crash Cushion	CCUS	X, Y and longitudinal distance
End Terminal	ETRM	X, Y and longitudinal distance
Transition	TRAN	X, Y and longitudinal distance

Format of Data Collection

The data shall be formatted per TABLE Z (requires Internet Explorer), which is an electronic spreadsheet that includes field names, metadata and example collection data.

Additional Guidelines

For each BARRIER feature, please describe the manufacturer and/brand information in the comments.

Key Contact

Please email questions and make data requests for BARRIERS to [redacted] at [redacted]

Figure 36. Traffic Barriers page of Minnesota DOT as-built website.

Incorporation of As-Built Data into Asset Management

Minnesota DOT's as-built program is directly linked to its asset management. In addition, a statewide asset-grade LiDAR survey was completed in 2017. The statewide survey was purposed to obtain traffic barrier information and was expanded to obtain a full inventory of assets within the state. LiDAR was proposed by most contractors and was the method used for the survey.

Fifteen thousand centerline miles of LiDAR information has been collected to date, helping to populate several asset inventories, including the asset classes indicated in the 2011.601 As-Built

Specification and Pay Item. The LiDAR survey collected location information and some asset attributes. The project also included a boots-on-the-ground assessment of traffic barrier defects. Spreadsheets with the asset and defect information were used to create map books. The map books are being utilized by Minnesota DOT crews to determine what they can fix and to prioritize the defects. All inventory and assessment data will be uploaded to TAMS.

As-Built Information Received from Third-Party Agencies

Minnesota DOT receives as-builts from contractors through an e-mail distribution list including the project manager and as-built experts. As-builts are typically sent as csv files. Of the 221 projects in the 2019 construction season, 109 include pay item 2011.601; therefore, contractor completed as-builts are not always necessary.

Virginia

As-Built Procedure Best Practices and Implemented Research

The Virginia Department of Transportation implemented a two-person system for tracking and verifying as-built plans. The developer of as-built plans varies according to the project delivery method, which will be discussed in the next section. Developers include Virginia DOT staff, consultants, design–builders, and contractors, depending on the project. The first three are much more common, and the contractor is typically only responsible for as-builts for specific and detailed project types such as intelligent transportation system (ITS) projects. The two-person system includes the as-built developer(s) and the as-built checker(s).

The as-built developer must record changes in MicroStation and save the file as a PDF. The individual responsible for checking and verifying the as-built plans reviews the PDF version. The checker verifies that numbers and notations are reasonable, and that the accuracy is adequate. The accuracy of as-builts is dependent on the field conditions, and there is not a standard accuracy requirement for all as-built plans.

As-builts as 3-D models are in discussion at Virginia DOT.

Varying As-Built Procedures According to Project Delivery Method

As stated previously, as-built procedures at Virginia DOT vary according to delivery method. The procedures for design–bid–build projects are well-established, while the procedures for design–build projects are not as well-established. Virginia DOT plans to develop a well-defined as-built development procedure for design–build projects in the future.

For design–bid–build projects, the district is responsible for as-built development. Virginia DOT employees develop the as-built plans for approximately 90% of these projects, while the remaining are developed by a hired consultant. Guidelines indicate that the individual responsible for developing as-builts must be a professional engineer. These as-builts must be completed in MicroStation and saved as a PDF. As-builts for design–bid–build projects are typically completed within 6 months of the completed project.

Design–build projects require as-built plans; however, there is no required procedure. As-builts are in the request for proposal and must be completed by the design–builder before they close out the project. Virginia DOT indicated the DOT intends for the procedure for as-built development for design–build projects to be different from those for design–bid–build projects.

As-Built Information on Warranties, Agreements, and Deployed Technology

Projects with warranties, agreements, or deployed technologies do not require additional or different as-built information than any other projects at Virginia DOT. However, as stated previously, contractors are most likely responsible for ITS project as-builts.

Incorporation of As-Built Data into Asset Management

Virginia DOT has an Asset Management Division; however, there is currently no systematic incorporation of as-built data into asset management.

As-Built Information Received from Third-Party Agencies

As stated, the majority of as-builts are completed by Virginia DOT staff; however, as-built data gathered from third-party agencies are typically received through e-mail. Some districts still require paper as-builts to be submitted, but for most districts electronic as-builts are preferred.

Wisconsin

As-Built Procedure Best Practices and Implemented Research

At Wisconsin DOT, the project staff develops as-built plans, whether that be in-house staff or consultants. Specifications indicate that as-built plans must be in PDF format; however, there is no requirement on the type of software used to develop the PDF plans. Wisconsin DOT implemented a pilot project testing the use of Bluebeam for developing as-built plans. Currently, it is estimated that approximately 75% of as-builts are developed using Adobe software, while 25% are developed using Bluebeam. However, Wisconsin DOT has recently downloaded Bluebeam to all employee computers, so it believes the percentage of as-builts developed using Bluebeam will increase. Bluebeam can perform measurements, embed photos, link other file types, and load more data than Adobe. Bluebeam can be used on iPads, enabling staff to develop as-builts in the field as the project progresses. Wisconsin DOT provided findings from the pilot project:

- Bluebeam on iPads is stripped down compared to the desktop version;
- It is a good tool for referencing, but as-builts developed using Bluebeam on iPads will most likely need to be cleaned up on the desktop version;
- Users found a slight improvement in as-built development using Bluebeam on iPads; and
- Using Bluebeam on iPads did not appear to save time when developing as-builts.

Wisconsin DOT also mentioned using 3-D modeling for as-builts for a megaproject in Milwaukee. For this project, a combination of in-house staff and consultants worked on the as-built 3-D models. This was unique to this specific project.

Wisconsin DOT has developed an as-built records management system (ARMS) for storing as-built plans. The project staff develops as-built plans using Adobe or Bluebeam and sends the completed plans to the regional office. Regional office staff upload the plans to ARMS, where they are then uploaded to the Wisconsin GIS database, DOTView. Once as-builts are uploaded to the GIS database, Wisconsin DOT employees can select an area in the database, and as-built plans within that area populate with information on when they were developed. Structural information is also searchable by Structure ID. Wisconsin DOT eventually plans to link ARMS and DOTView with asset management information.

Varying As-Built Procedures According to Project Delivery Method

Different projects at Wisconsin DOT may have different approaches to as-built development, such as using 3-D models for the megaproject in Milwaukee. However, Wisconsin DOT is only allowed to perform design–bid–build projects; therefore, there is no variation in project delivery method.

As-Built Information on Warranties, Agreements, and Deployed Technology

Projects with warranties, agreements, or deployed technologies do not require additional or different as-built information than any other projects. However, specific and detailed work such as electrical work may require the contractor to provide as-builts.

Incorporation of As-Built Data into Asset Management

As mentioned early in this section, Wisconsin DOT hopes to incorporate asset management into its ARMS and its GIS database. Currently, it has applications monitoring inventory such as signs and signals. This information is monitored in the asset database managed by the Office of Asset Management. Ideally, this information will be added to the GIS database and will be viewable in DOTView, along with the as-built information. This allows for the asset information to be located spatially.

As-Built Information Received from Third-Party Agencies

Wisconsin DOT receives as-built information from third-party agencies in all ways. However, by permit, as-builts should be delivered by e-mail as a PDF. Wisconsin DOT has discussed applying as-built standards in the permit process requiring as-builts to be sent as CAD files with a certain accuracy.

Challenges Faced

After the interviews, it seemed in the best interest of the interviewees to report some findings as general and anonymous. All interviewees indicated challenges they and their STAs have faced while developing, preserving, and using as-built plans. The following is a compiled list of challenges faced across all six STAs that were interviewed.

- Limited time,
- Limited resources,
- Insufficient as-built guidelines,
- Limited capabilities of staff,
- Difficulty collecting as-built information in the format needed by end users,
- Digital transition of the industry makes development difficult,
- Value of as-builts is often not recognized until several years after their development,
- No verification of whether as-builts are completed and stored,
- As-builts are not fully compatible with other softwares,
- Making as-builts public can be a homeland security issue, and
- Accuracy of as-builts is often not quantified.

CHAPTER 5

Conclusions

This chapter of the synthesis summarizes the findings of this project and draws conclusions on as-built procedures that are in place at STAs. The objectives of this synthesis were to document the procedures used by STAs to develop and update as-built plans for various delivery methods; identify methods and technologies used for developing, preserving, and updating as-built plans; determine who is using as-built plans after they are approved and for what purposes; examine how STAs store and retrieve approved as-built plans for legal purposes; determine how STAs capture as-built information from third-party agencies such as contractors, design consultants, and CEI consultants; and determine areas of research and future improvement. The synthesis study methodology used surveys of STAs to establish a state of the practice regarding as-built procedures. The survey was sent to members on the AASHTO Subcommittee on Construction and the AASHTO Subcommittee on Design. A response rate of 84% (42 states) was recorded.

In addition to the survey, STAs were chosen through the literature review and by initial survey responses for follow-up interviews. Six states were interviewed using Zoom conferencing. The interviewees were selected not only to achieve diversity in size and complexity of the agencies, but also to question those with differing as-built procedures. The states selected were Arizona, Colorado, Kentucky, Minnesota, Virginia, and Wisconsin. The case example interviews provided information on as-built procedures at these STAs in detail.

Key Findings

The work produced several key findings. Half of the respondents indicated that their agencies had a documented definition of as-built plans. The majority of the surveyed STAs have documented procedures for as-built development and storage procedures. However, fewer STAs (39% of respondents) have documented as-built approval procedures.

As-Built Development

- *The focus of as-builts is documenting changes made to the design plans during the construction process.* While responses varied on what information is being recorded on as-built plans, 74% of respondents (31 of 42) indicated they recorded all changes made during construction that deviate from the original plans.
- *The majority of STAs indicate that as-built information is recorded using handwritten notes, but this is often supplemented with other technology.* Thirty-six STAs indicated they are still recording as-built information as handwritten notes, which is interesting considering the technological advances within the industry. Survey respondents noted that sometimes handwritten notes and markups are the most convenient and time-efficient way to record as-built information. However, of the respondents who indicated they are recording as-built information

by hand, 89% are also using other methods and technologies to capture as-built information. This is an indication that, while the methods used for as-built development may be less technologically sound than that of original project plans, there is a movement under way to incorporate newer technologies.

- *Systems used to develop as-built plants vary across STAs.* Twenty-eight still rely on paper mark-ups as as-built plans, 18 use Adobe, 17 use Bluebeam, and 16 use MicroStation. Only three STAs use 3-D modeling to record as-built information.
- *STAs construction personnel are still involved in the majority of the as-built development process.* Fifty-two percent (52%) of STAs utilize only in-house employees for as-built development, 45% utilize in-house employees and outside agencies, and 3% utilize only outside agencies. Outside agencies consisted of either the contractor or a design consultant. Most STAs using an outside agency to develop as-built plans are utilizing the contractor.
- *The process of as-built development is largely uniform across STAs regardless of delivery method.* The only substantial trend noticed is that 55% of STA survey respondents indicated that the entity responsible for as-built development varies according to delivery method.

As-Built Approval

- *The majority of responding STAs did not indicate having a formal as-built approval process.* Only 39% of STA survey respondents indicated they had a documented as-built approval process. Little information was provided by STAs regarding their approval processes. Information that was provided consisted of the individual(s) responsible for signing completed as-built plans, therefore approving them.

As-Built Retention and Preservation

- *As-built storage continues to evolve at STAs, with most states migrating to electronic storage systems.* However, the accessibility and operability of the current electronic storage systems could be improved. Seventy-five percent (75%) of STA survey respondents indicated they had a documented as-built storage procedure.
- *The legal considerations of as-builts do not appear to be a significant concern for responding STAs.* However, homeland security issues do limit the availability of critical-infrastructure as-built plans to the public.

Uses of Approved As-Built Plans

- *Uses of as-built plans still fall under traditional use scenarios (e.g., informing preliminary design), but some states are incorporating as-builts into asset management systems.* No STAs indicated they establish accuracy requirements for their as-built plans. Uses of approved as-builts seem to vary depending on the section or department using the as-builts. Fifty-one percent (51%) of STA survey respondents use as-built plans for all project types, 29% use as-builts for new design projects, and 3% (one agency) use as-builts for maintenance projects only. The most used as-built information from the survey responses was typical section information.

Future Study Needs

Based on the results of this study, the following suggestions for future work in this area are offered:

- *Improvements in as-built data capture methods were the most frequently cited (94% of respondents) area of needed improvement in current STA as-built processes.* It appears that STAs realize

that new technology could improve the efficiency of as-built data collection, but adoption has been slow and piecemeal compared to other sectors of the construction industry.

- *STAs are currently improving as-built processes with a focus on improving the overall efficiency of the as-built creation process.* Eighteen STAs indicated they are currently updating their as-built processes with a focus on improving usability (70%), incorporating new technology (68%), and better linking to asset management systems (68%). There does not appear to be a focus on modifying the as-built process across delivery methods.
- *The most significant obstacles that STAs face in improving their current as-built process are limitations in staff knowledge and technology.* Survey respondents noted lack of technical staffing (52%), IT issues (32%), and lack of available technology as the biggest challenges to improving their current as-built process.
- *STAs could also benefit from better methods to incorporate as-built data into asset management systems.* As-built information can become outdated as maintenance projects repair existing facilities. Methods or technologies that can provide more up-to-date asset management data could be beneficial.

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APPENDIX A

Survey Questionnaire

NCHRP TOPIC 50-12 SURVEY QUESTIONNAIRE
NOVEMBER 2018

Synthesis [Topic] 50-12 seeks to document how as-built plans are developed, used, and updated for State Transportation Agencies (STAs). The synthesis will attempt to document how STAs define as-built plans. It will also attempt to document what information is being included on STA as-built plans and methods used to capture such information. Additional information gathered will include platforms and entities used to develop as-built plans, approval and preservation of as-builts, uses of approved as-built plans, retrieval of as-built information for legal purposes, transfer of as-built information from third-party agencies, and differences in as-built plans for various project types such as Design–Bid–Build, Design–Build, Construction Manager/General Contractor, and Public-Private Partnerships.

General Information

1. Does your agency use a documented procedure for developing as-built plans?
   ☐Yes ☐No
2. Please attach any as-built development documentation below.
   Click here to enter text.
3. Does your agency use a documented procedure for approving as-built plans?
   ☐Yes ☐No
4. Please attach any as-built approval documentation below.
   Click here to enter text.
5. Does your agency use a documented procedure for storing as-built plans?
   ☐Yes ☐No
6. Please attach any as-built storage documentation below.
   Click here to enter text.
7. Does your agency have a documented definition of as-built plans?
   ☐Yes ☐No ☐Unsure
8. Please attach your agency's definition of as-built plans.
   Click here to enter text.

As-Built Development Questions

9. Which entity is responsible for developing your agency's as-built plans?
   ☐Construction
   ☐Design
   ☐Contractor
   ☐Design Consultant
   ☐Other Click here to enter text.

10. Does the entity responsible for as-built development vary according to delivery method (e.g. Design–Bid–Build, Design–Build, Construction Management/General Contractor, Public-Private Partnership)?

☐Yes, entity varies ☐No, same entity for all delivery methods

11. What information is recorded on your agency's as-built plans? (Please check all that apply)

☐All changes made during construction
☐Changes in horizontal and vertical alignment
☐Grade revisions
☐Corrections and adjustments to stationing
☐Changes to typical sections
☐Utility locations, depths, elevations, offsets, and clearances
☐Changes to right-of-way lines, distances, and markers
☐Changes to drainage structures such as length, flow line elevation, station or offset dimensions, sizes, thicknesses, and types of inlets and manholes
☐Location and elevation of monuments, benchmarks, freeway fences, and gates
☐Locations and dimensions of all structures
☐ Foundation elevations and subsurface structural details
☐Other Click here to enter text.

12. What methods or procedures does your agency use to capture and document as-built information? (Please check all that apply)

☐Hand written notes
☐Electronic notes
☐Photographs
☐Google Earth
☐LiDAR
☐Ground Penetrating Radar
☐Drones
☐3-D Models
☐Other Click here to enter text.

13. What platforms (technologies) does your agency use to establish as-built plans? (Please check all that apply)

☐Microfilm/fiche
☐Paper mark ups
☐Mylar sheets
☐Adobe
☐Bluebeam
☐AutoCAD
☐MicroStation
☐3-D Modeling
☐Other Click here to enter text.

14. In reference to percent of project completion, when does your agency begin to develop as-built plans?

☐Beginning of project
☐25% project completion
☐50% project completion
☐75% project completion
☐ After project is complete

15. Does your agency assign quality and/or accuracy levels to as-built plans to inform users of the degree to which the information was recorded?

☐Yes ☐No ☐Unsure

16. Please attach any documentation describing your agency's as-built quality and/or accuracy levels.
Click here to enter text.

As-Built Approval Questions

17. Do you have any comments you want to provide about your agency's as-built approval process?
☐Yes Click here to enter text. ☐No

As-Built Storage Questions

18. Where does your agency store approved as-built plans? (Please check all that apply)
☐Central Office as hard copy prints
☐District Offices as hard copy prints
☐Central Office as electronic files
☐District Offices as electronic files
☐Electronic Document Management System
☐Project Archives
☐Other Click here to enter text.

19. If your agency stores as-built plans electronically, please list the system (e.g. ProjectWise, FileNet, Computer Hard Drive, etc.) used by your agency.
Click here to enter text.

20. Are your agency's as-built plans updated to reflect changes made to facilities after construction completion?
☐Yes ☐No ☐Unsure

As-Built Usage Questions

21. Who has access to your agency's as-built plans? (Please check all that apply)
☐Certain departments within the agency
☐Anyone within the agency
☐Other State Transportation Agencies
☐Federal agencies (e.g. Federal Highway Administration)
☐General Public

22. For what project types is your agency using approved as-built plans? (Please check all that apply)
☐Highway Maintenance
☐Highway Design
☐Bridge Maintenance
☐Bridge Design
☐Other Click here to enter text.

23. What information is your agency using from approved as-built plans? (Please check all that apply)
☐Pile Tip Elevations
☐Beam Set Information
☐X Dimensions
☐Culvert Fill Heights
☐Foundation Layouts
☐Actual Courses Placed
☐Typical Sections
☐Subgrade Details
☐ADA Ramps Information

☐Intersection Grades
☐Maintenance History
☐Right-of-Way Plans
☐Pictures and/or LiDAR Scans
☐Alignments
☐Footing Information
☐Pile Lengths
☐Stationing Information
☐Bearing Details
☐Rock Cut Slopes
☐Cut and Fill Slopes
☐Subsurface Utility Information
☐Depths and clearances
☐Other Click here to enter text.

Future Opportunities

24. Does your agency plan to develop or refine as-built procedures in the near future?
☐Yes ☐No ☐Unsure
25. Which aspects of the as-built process (check all that apply)?
☐Entity developing as-built plans
☐Information being included on as-built plans
☐Method used to capture as-built information
☐Platform used to establish as-built plans
☐When as-built plans are developed
☐Approval process for as-built plans
☐Storage location of completed as-built plans
☐Naming convention of stored as-built plans
☐Uses of as-built plans
☐Other Click here to enter text.
26. Which of the following do you view as necessary improvements to your current as-built procedures?
☐Improved accuracy of as-builts
☐Improved usability of as-builts
☐Updated procedures to reflect newly available technology
☐Adaptability to multiple delivery methods
☐Increased feedback/communication between agency divisions
☐Better linkage to asset management
☐Other Click here to enter text.
27. What key challenges is your agency facing in making improvements to as-built procedures? (Please check all that apply)
☐IT Issues
☐Lack of technical staffing
☐Lack of management support
☐Uncertainty on where to begin
☐Lack of available technology
☐Other Click here to enter text.
28. Is there any information you would like to add about as-builts?
☐Yes Click here to enter text. ☐No

Case Example Participation

29. This synthesis will include six case examples to document different as-built practices being used. Would your agency be interested in participating in a case example?

☐Yes ☐No

The survey is complete. Thank you for your participation!

APPENDIX B

Aggregated Survey Results

Q1 - Does your agency use a documented procedure for developing as-built plans?

#	Answer	%	Count
1	Yes	69.05%	29
2	No	23.81%	10
3	Unsure	7.14%	3
	Total	100%	42

Q3 - Does your agency use a documented procedure for approving as-built plans?

#	Answer	%	Count
1	Yes	38.10%	16
2	No	54.76%	23
3	Unsure	7.14%	3
	Total	100%	42

Q5 - Does your agency use a documented procedure for storing as-built plans?

#	Answer	%	Count
1	Yes	75.00%	30
2	No	25.00%	10
3	Unsure	0.00%	0
	Total	100%	40

Q7 - Does your agency have a documented definition of as-built plans?

#	Answer	%	Count
1	Yes	50.00%	20
2	No	37.50%	15
3	Unsure	12.50%	5
	Total	100%	40

Q9 - Which entity is responsible for developing your agency's as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Construction	85.71%	36
2	Design	16.67%	7
3	Contractor	38.10%	16
4	Design Consultant	21.43%	9
5	Other	9.52%	4
	Total		42

Q9_5_TEXT - Other

Other - Text
Bridge Program
The Erosion Control Group
Contractor only applies to Design–Build
Regarding question 10, the contractor is involved with as-built plans in design build and public private partnership but no construction manager/general contractor
Construction Engineering & Inspection
Resident Engineer

Q10 - Does the entity responsible for as-built development vary according to delivery method (e.g. Design–Bid–Build, Design–Build, Construction Management/General Contractor, Public-Private Partnership)?

#	Answer	%	Count
1	Yes, entities vary	55.26%	21
2	No, same entity for all delivery methods	44.74%	17
	Total	100%	38

Q11 - What information is recorded on your agency's as-built plans? (Please check all that apply)

#	Answer	%	Count
1	All changes made during construction	73.81%	31
2	Changes in horizontal and vertical alignment	54.76%	23
3	Grade revisions	50.00%	21
4	Corrections and adjustments to stationing	52.38%	22
5	Changes to typical sections	50.00%	21
6	Utility locations, depths, elevations, offsets, and clearances	33.33%	14
7	Changes to right-of-way lines, distances, and markers	40.48%	17
8	Changes to drainage structures such as length, flow line elevation, station or offset dimensions, sizes, thicknesses, and types of inlets and manholes	61.90%	26
9	Location and elevation of monuments, benchmarks, freeway fences, and gates	38.10%	16
10	Locations and dimensions of all structures	52.38%	22
11	Foundation elevations and subsurface structural details	54.76%	23
12	Other	7.14%	3
	Total		42

Q11_12_TEXT - Other

Other - Text
All corrections, repairs, revisions and additional details necessary to depict the work as it was constructed.
Anything that could have an effect on future project development activities
Electrical pull boxes and other electrical items, minimum vertical clearance, pavement lanes, sidewalk, islands, median openings, utility crossings, irrigation crossings

Q12 - What methods or procedures does your agency use to capture and document as-built information? (Please check all that apply)

#	Answer	%	Count
1	Hand written notes	85.71%	36
2	Electronic notes	76.19%	32
3	Photographs	33.33%	14
4	Google Earth	9.52%	4
5	LiDAR	9.52%	4
6	Ground Penetrating Radar	7.14%	3
7	Drones	2.38%	1
8	3-D Models	7.14%	3
9	Other	7.14%	3
	Total		42

Q12_9_TEXT - Other

Other - Text
Transitioning from paper As-Built plans to electronic As-Built plans.
CAD files, Survey data files
Contractor survey records
LiDAR and GPR are available but not used for as-built plans as a rule.

Q13 - What platforms (technologies) does your agency use to establish as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Microfilm/fiche	11.90%	5
2	Paper mark ups	66.67%	28
3	Mylar sheets	9.52%	4
4	Adobe	42.86%	18
5	Bluebeam	40.48%	17
6	AutoCAD	9.52%	4
7	MicroStation	38.10%	16
8	3-D Modeling	7.14%	3
9	Other	4.76%	2
	Total		42

Q13_9_TEXT - Other

Other - Text
Paper As-Built plans are stored via microfiche and electronic As-Built plans are stored in OnBase (Hyland Software, Inc.)
We currently allow paper markups of as-built plans, but we are in the process of updating as-built documentation procedures to electronic documentation only. This will be done by using Adobe.
Primarily Spicer Imagination software (through Citrix) but also utilize a few available Bluebeam licenses

Q14 - In reference to percent of project completion, when does your agency begin to develop as-built plans?

#	Answer	%	Count
1	Beginning of project	58.97%	23
2	25% project completion	0.00%	0
3	50% project completion	2.56%	1
4	75% project completion	5.13%	2
5	After project is complete	30.77%	12
6	Varies by Project	2.56%	1
	Total	100%	39

Q15 - Does your agency assign quality and/or accuracy levels to as-built plans to inform users of the degree to which the information was recorded?

#	Answer	%	Count
1	Yes	5.26%	2
2	No	84.21%	32
3	Unsure	10.53%	4
	Total	100%	38

Q17 - Do you have any comments you want to provide about your agency's as-built approval process?

#	Answer	%	Count
1	Yes	36.84%	14
2	No	63.16%	24
	Total	100%	38

Q17_1_TEXT - Yes

Yes - Text
We have a process, but it doesn't work very well and is often an issue at project closeout. In general, accuracy is not good.
Delaware is starting to experiment with Bluebeam and may be using it for as-builts in the future.
THE NDDOT as-built process was recently amended to be electronic. We also developed a web based access system that pulls as-built plans from official storage location for easy retrieval. Previously all as-built plans were handwritten paper copies that were not stored in one central location.
Our as-built process is continually being updated as projects are developed and information is requested from our customers. One of the important developments in our agency's process has been an as-built web page that has all of the information (in one location) pertaining to the development and retrieval procedures of as-built. This allows for more consistent submittals.
We are currently updating our as-built plan process. The manual that has been attached in this survey will be changing to reflect the revisions to our process.
As-built process is documented in Michigan Road Design Manual section 14.73.
Completed as-built plans are signed and sealed by the Resident Construction Engineer/ Project Engineer.
We are standardizing the procedure for the Design/Build projects.
Process is antiquated, and project personnel, whether ALDOT or consultant, have quit doing. We are looking at pilot projects using software such as PlanGrid and Procore, to help us update our procedures and be able to capture this data on inspectors' iPads as it happens. Then, utilize that data for asset management by Maintenance.
The As-Builts are done by our Construction personnel, but then are checked by our Engineering Audit personnel during the audit process.
Our agency doesn't approve as-builts. The Region Records Coordinator makes sure the PDF opens properly and correct labels appear on the title sheet before uploading to electronic storage.
The approval process is included in the record plans procedure documents uploaded earlier.
Looking to move forward with ProjectWise to store documents in the future.

Q18 - Where does your agency store approved as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Central Office as hard copy prints	21.43%	9
2	District Offices as hard copy prints	35.71%	15
3	Central Office as electronic files	38.10%	16
4	District Offices as electronic files	21.43%	9
5	Electronic Document Management System	54.76%	23
6	Project Archives	11.90%	5
7	Other	0.00%	0
	Total		42

Q19 - If your agency stores as-built plans electronically, please list the system (e.g. ProjectWise, FileNet, Computer Hard Drive, etc.) used by your agency.

If your agency stores as-built plans electronically, please list the system (e.g. ProjectWise, FileNet, Computer Hard Drive, etc.) used by your agency.
Microsoft Access
OnBase (Hyland Software, Inc.)
Internal network drives; ProjectWise
ProjectWise
Falcon Document Management System
Electronic Content Management System
ProjectWise
Filenet
ProjectWise and computer hard drive. Made public on Cabinet's website
Web cloud location and local servers.
ProjectWise
Filenet
EDMS
ME-Plans
ProjectWise
Computer Hard Drive and unsure of System(s) used.
Falcon-Plan Library
ProjectWise
In-house developed system known as ERMS (Electronic Records Management System)
ProjectWise
ProjectWise
ProjectWise
Falcon/DMS software from tsaADVET, Inc.
Computer Network Drive
As-built Access Database and As-builts Records Management System (ARMS) are used to make as-builts available in Department of Transportation Viewer (DOTView) and Highway Structures Information System (HSI).
Bentley ProjectWise InterPlot Server Digital Print Room (DPR)
Electronic Document Management System
SharePoint project sites

Q20 - Are your agency's as-built plans updated to reflect changes made to facilities after construction completion?

#	Answer	%	Count
1	Yes	10.53%	4
2	No	76.32%	29
3	Unsure	13.16%	5
	Total	100%	38

Q21 - Who has access to your agency's as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Certain departments within your agency	13.16%	5
2	Anyone within your agency	86.84%	33
3	Other State Transportation Agencies	18.42%	7
4	Federal agencies (e.g. Federal Highway Administration)	34.21%	13
5	General Public	23.68%	9
	Total		38

Q22 - For what project types is your agency using approved as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Highway Maintenance	57.89%	22
2	Highway Design	84.21%	32
3	Bridge Maintenance	60.53%	23
4	Bridge Design	81.58%	31
5	Other	7.89%	3
	Total		38

Q22_5_TEXT - Other

Other - Text
Litigation
Our agency doesn't approve as-built plans, but we do use as-built information for future maintenance and design projects, verifying information and supplementing with additional survey as necessary.

Q23 - What information is your agency using from approved as-built plans? (Please check all that apply)

#	Answer	%	Count
1	Pile Tip Elevations	63.16%	24
2	Beam Set Information	36.84%	14
3	X Dimensions	36.84%	14
4	Culvert Fill Heights	55.26%	21
5	Foundation Layouts	60.53%	23
6	Actual Courses Placed	44.74%	17
7	Typical Sections	73.68%	28
8	Pile Length	57.89%	22
9	ADA Ramps Information	44.74%	17
10	Intersection Grades	57.89%	22
11	Maintenance History	26.32%	10
12	Right-of-Way Plans	44.74%	17
13	Pictures and/or LiDAR Scans	21.05%	8
14	Alignments	73.68%	28
15	Footing Information	68.42%	26
16	Other	10.53%	4
17	Stationing Information	71.05%	27
18	Bearing Details	52.63%	20
19	Rock Cut Slopes	39.47%	15
20	Cut and Fill Slopes	55.26%	21
21	Subsurface Utility Information	52.63%	20
22	Depths and clearances	60.53%	23
23	Subgrade Details	60.53%	23
	Total		38

Q23_16_TEXT - Other

Other - Text
Unsure
Location/Elevation modifications; Addition of minor items (sign, inlet box, cross drain pipe, etc.)
All relevant data
Varies project to project

Q24 - Does your agency plan to develop or refine as-built procedures in the near future?

#	Answer	%	Count
1	Yes	47.37%	18
2	No	18.42%	7
3	Unsure	34.21%	13
	Total	100%	38

Q25 - Which aspect of the as-built process does your agency plan to develop or refine (Please check all that apply)?

#	Answer	%	Count
1	Entity developing as-built plans	22.22%	4
2	Information being included on as-built plans	61.11%	11
3	Method used to capture as-built information	94.44%	17
4	Platform used to establish as-built plans	55.56%	10
5	When as-built plans are developed	27.78%	4
6	Approval process for as-built plans	50.00%	8
7	Storage location of completed as-built plans	55.56%	9
8	Naming convention of stored as-built plans	33.33%	5
9	Uses of as-built plans	33.33%	5
10	Other	16.67%	2
	Total		18

Q25_10_TEXT - Other

Other - Text

3-D Model Requirements

Reviewing potential implementation of Bluebeam, and additional electronic documentation capabilities (coordinates, photos, etc.)

Q26 - Which of the following do you view as necessary improvements to your current as-built procedures? (Please check all that apply)

#	Answer	%	Count
1	Improved accuracy of as-builts	56.76%	21
2	Improved usability of as-builts	70.27%	26
3	Updated procedures to reflect newly available technology	67.57%	25
4	Adaptability to multiple delivery methods	18.92%	7
5	Increased feedback/communication between agency divisions	48.65%	18
6	Better linkage to asset management	67.57%	25
7	Other	10.81%	4
	Total		37

Q26_7_TEXT - Other

Other - Text
Ability to be viewed by general public
Capture asset data
We are researching the possibility of going plan less with the use of 3-D Models. This will impact all aspects including how we handle as-builts.

Q27 - What key challenges is your agency facing in making improvements to as-built procedures? (Please check all that apply)

#	Answer	%	Count
1	IT Issues	32.26%	10
2	Lack of technical staffing	51.61%	16
3	Lack of management support	6.45%	2
4	Uncertainty on where to begin	25.81%	8
5	Lack of available technology	32.26%	10
6	Other	25.81%	8
	Total		31

Q27_6_TEXT - Other

Other - Text
Deciding which technology to use and where to store to maximize awareness of existing as-builts
Unsure
Training staff how and when to record as-builts
Culture. Paper vs. electronic
Records retention policies
Old process has yet to become an issue. Impetus to change isn't there.
Resource issues
Time
Training of the personnel developing the as-built plans

Q28 - Is there any information you would like to add about as-builts?

#	Answer	%	Count
1	Yes	13.16%	5
2	No	86.84%	33
	Total	100%	38

Q28_1_TEXT - Yes

Yes - Text
The attachment added for question #5 is incorrect but could not be removed from the response. Our current processes and procedures are loosely defined. There are many areas where improvements could be implemented.
The rollout of the web-based system received high remarks. As existing as-built paper plans are created into electronic and placed into document management system storage location the remarks will be even greater.
Link to Iowa DOT Construction Manual Chapter 2.72 guidance for as-built plans: https://iowadot.gov/erl/current/CM/content/CM%202.70.htm
Our current procedures are sound. Our future improvements include the development of as-builts using 3-D/AMG technology.
Our procedures are very informal. Most districts have a set of marked-up construction plans notated major changes. No formal process requires this, but usually a practice conducted by the individual districts.

Q29 - This synthesis will include five case examples to document different as-built practices being used. Would your agency be interested in participating in a case example?

#	Answer	%	Count
1	Yes	21.62%	8
2	No	78.38%	29
	Total	100%	37

APPENDIX C

Case Study [Example] Interview Questions

Arizona

1. Please explain how the entity responsible for as-built development varies by delivery method.
2. Does your agency collect as-built information on warranties, agreements, and deployed technology?
3. If your agency is incorporating as-built data into asset management, please explain.
4. How is litigation using as-built plans?
5. Please explain your as-built webpage and what it entails.

Colorado

1. Do the contractor, construction employees, and a construction consultant project engineer all assist in developing as-builts for any given project or does it vary per project?
2. Does your agency collect as-built information on warranties, agreements, and deployed technology?
3. If as-built development occurs at different phases of construction according to delivery method, please explain.
4. If your agency is incorporating as-built data into asset management, please explain.
5. Why do you think as-builts are not being done consistently even though Colorado DOT has a documented procedure?

Kentucky

1. Please explain how the entity responsible for as-built development varies by delivery method.
2. Does your agency collect as-built information on warranties, agreements, and deployed technology?
3. If your agency is incorporating as-built data into asset management, please explain.
4. Please explain your quality/accuracy levels for as-built plans.

Minnesota

1. Please describe your processes, challenges, and aspirations with your asset management and statewide asset grade LiDAR survey.
2. How is the data used in regard to as-built information?
3. Does your agency collect as-built information on warranties, agreements, and deployed technology?

Virginia

1. Please explain how the entity responsible for as-built development varies by delivery method.
2. Is the standardized as-built procedure your agency is developing for design/build projects different than that of other delivery methods? If so, please explain.
3. Does your agency collect as-built information on warranties, agreements, and deployed technology? If yes, please explain.
4. According to your survey response, Virginia is still establishing as-built plans as microfilm. Is there a reason behind this storage method?
5. If your agency is incorporating as-built data into asset management, please explain.
6. According to your survey response, as-builts are not completed until after the project is complete. Does the entity responsible for as-built development have designated time/resources to complete as-builts after the completion of the project? Is there a time frame in which as-builts must be submitted?
7. Please explain your quality/accuracy levels for as-built plans.

Wisconsin

1. If as-built development differs according to delivery method, please explain.
2. Does your agency collect as-built information on warranties, agreements, and deployed technology? If yes, please explain.
3. If your agency is incorporating as-built data into asset management, please explain.
4. Please explain your as-built access database and as-built records management system.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, NW
Washington, DC 20001

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